FINNISH ROAD ADMINISTRATION

Jari Pihlajamäki, Janne Sikiö

HVS-NORDIC
Reseach Report No 2

Tests 09-10, high trafficked pavements on Ring Road II

Finnra Reports 29/2001

VTT
Technical Research Centre of Finland

Swedish National Road Administration

Swedish Road and Transport Research Institute

Jari Pihlajamäki, Janne Sikiö

HVS-NORDIC
Reseach Report No 2

Tests 09-10, high trafficked pavements on Ring Road II

Finnra Reports 29/2001

Finnish Road Administration
Helsinki 2001

ISSN 1457-9871
ISBN 951-726-764-9
TIEH 3200675E

Edita Oyj
Helsinki 2001

This Publication is available at Finnra Publications Sales
telefax int. +358 (0)204 22 2652
e-mail julkaisumyynti@tiehallinto.fi
www.tiehallinto.fi/julk2.htm

Finnish Road Administration
Opastinsilta 12 A
P.O.Box 33
FIN-00521 HELSINKI
Tel. int. +358 (0)204 22 11

Jari PIHLAJAMÄKI, Janne SIKIÖ. HVS-NORDIC. HVS-NORDIC. Research Report No2. Tests 09 - 10, high trafficked pavements on Ring Road II. Finnish Road Administration, Finnra Reports 29/2001. 40 p. + app. ISBN 951-726-764-9, ISSN 1457-9871, TIEH 3200675E

Key words: pavement, bearing capacity, stress, measuring, test methods, strain gauge, deterioration, durability, economic efficiency

Clasification: 32

ABSTRACT

Finland and Sweden have jointly invested in HVS-NORDIC, which is a mobile Accelerated Loading Test facility with full temperature control. A six-year period of research collaboration between 1997 and 2003 has been agreed. The activity of the first period in Finland is described in the Periodic Report. This research report describes the study of two high trafficked pavements tested on Ring Road II in Espoo.

The tested pavement structures were instrumented with strain sensors in bituminous layers, stress sensors in unbound granular base layer, total deflection sensors and temperature sensors. Initial response measurements with different parameters were made, and measurements during testing as well. These are important data for analysis and modelling.

The aim of the tests was to study two different road structures for heavy trafficked roads, a conventional road structure, and a new innovative one. The test structures vary only by bound layers. The research idea of innovative structure was that the lowest bound layer had high resistance to fatigue and the next asphalt concrete binder course was very stiff.

Based on response values and laboratory fatigue criteria, innovative structure had 30 times better resistance to traffic loading, relatively. However, the construction costs of bituminous layers were only 11 % higher for innovative structure. The same life time than 110 mm thick conventional structure had, can be reached with 80 mm thick innovative structure. Calculations are made according to similar way described above. Thus the construction costs are 17 % lower for innovative structure compared to those of conventional one.

According to APAS calculations the fatigue life of innovative structure was twice compared to that of conventional one. Innovative structure with 110 mm bituminous layers was 6 % and with 80 mm bituminous layers 7 % more economic compared to conventional structure with 110 mm bituminous layers, when analysis was made based on equivalent uniform annual cost (EUAC).

The materials and structure of innovative structure are well known and tested. There are no limitations to construct such pavements in practice.

FOREWORD

Finland and Sweden have jointly invested in HVS-NORDIC, which is a mobile Accelerated Loading Test facility with full temperature control. The HVS-NORDIC research is a part of the Finnish National Road Structures Research Programme, TPPT, which is funded by the Finnish Road Administration (Finnra). The HVS-NORDIC research is being carried out in co-operation with the Swedish National Road and Transport Research Institute (VTI), and the Swedish National Road Administration (SNRA). HVS-Nordic has been in Finland in 1997-1998, 1998-2000 in Sweden and from November 2000 in Finland.

The research is reported first in Weekly Reports (main results by e-mail), then in Periodic Reports, which include preliminary results after each period, and later in Research Reports and Conference Papers. This Research Report covers tests 9-10 and describes the study of two high trafficked pavements tested on Ring Road II in Espoo.

The members of the HVS team in this study were Matti Huhtala, Jari Pihlajamaki, Pekka Halonen, Veikko Miettinen, Risto Alkio, Juhani Idman, Heikki Kangas and Janne Sikio.

The report was written by Jari Pihlajamaki and Janne Sikio and was compiled according to the guidelines given by Aarno Valkeisenmaki (Finnish Road Enterprise) and Kari Lehtonen (Finnra).

ABBREVIATIONS

APT	Accelerated Pavement Testing
HVS	Heavy Vehicle Simulator
Finnra	Finnish Road Administration
VTT	Technical Research Centre of Finland
SNRA	Swedish National Road Administration
VTI	Swedish Road and Transport Research Institute
NVF	Nordic Road Association
OECD	Organisation for Economic Co-operation and Development
STRO	Scandinavian Tyre and Rim Organisation
TPPT	Finnish National Road Structures Research Programme
LCPC	Laboratoire des Ponts et Chaussées, France
CAPTIF	APT facility in New Zealand
FWD	Falling Weight Deflectometer
AC	Asphalt Concrete
ACB	Asphalt Concrete in base course
ACBi	Asphalt Concrete in binder course
SMA	Split mastic asphalt
AC20	Asphalt Concrete, maximum grain size 20 mm
B80	Bitumen, penetration 80
Q1	Quality class of base course material
Q2	"
Q3	"

CONTENTS

1. INTRODUCTION

1.1. Background

There was need to develop new constructions for heavy trafficked roads in Finland. The cross weight of heavy vehicles has increased, new axle and tyre types, especially wide-base tyres instead of dual wheels have appeared on roads, and tyre inflation pressure has increased. All these changes are more and more aggressive to pavements.

An accelerated pavement-testing facility, Heavy Vehicle Simulator (HVS), was bought from South Africa in 1996. It is owned on a 50/50 basis by Sweden (VTI) and Finland (VTT and Finnra). A six-year period of research collaboration between 1997 and 2003 has been agreed /1/. The co-operation is organized on three levels with steering, programme and operative groups.

The HVS-NORDIC was used in Finland during 1997—98 and in Sweden, 1998—2000. The activity of the first period in Finland is described in the Periodic report /2/. This Research Report covers tests 9-10 and describes the study of two high trafficked pavements tested on Ring Road II in Espoo.

1.2. Technical specifications of the machine

The machine is called HVS-NORDIC. The HVS Mark IV is a mobile full-scale accelerated pavement-testing facility (Figure 1), whose loading is linear. It can be run over a short distance by itself at walking speed, in practice only at the same test site. It can be moved as a semi-trailer over longer distances to other test areas or to VTI in Sweden. Since it has steering wheels, it can turn even relatively sharp corners, in spite of its long length. Its highway speed is 50 km/h, and special permits are needed.

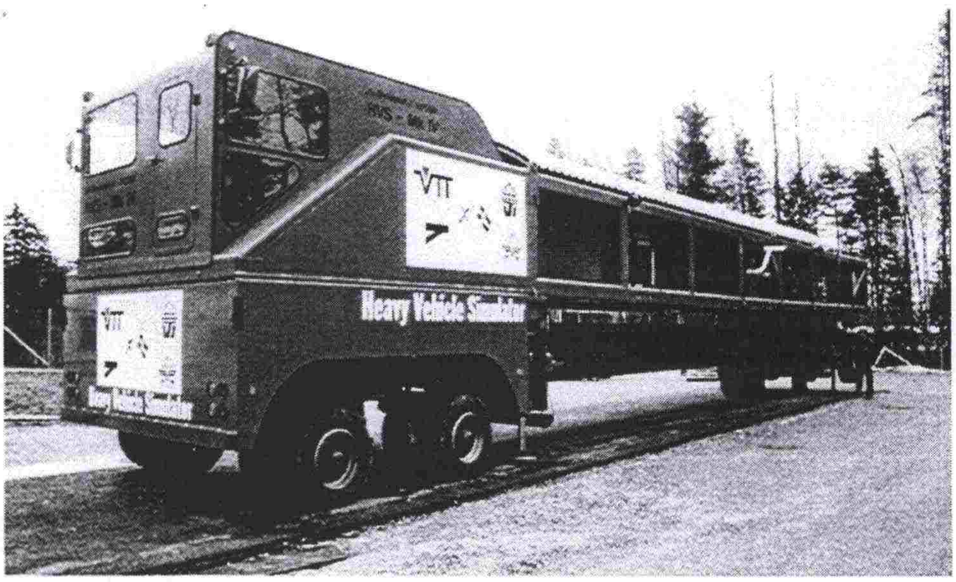

Figure 1. HVS machine.

The HVS-NORDIC has a heating/cooling system and thus temperature can be kept constant. The air temperature inside the heating/cooling box is controlled in order to keep the pavement temperature constant. The standard temperature of bituminous layers is selected to be +10°C. The HVS can be run by diesel engine or by electric motor. The diesel engine also provides power for the heating/cooling system, which means it is not dependent on external power.

The main technical characteristics are: length 23 m, width 3.5 m, height 4.2 m and weight 46 t. The loading wheels are dual or single; the standard dual wheel type is 295/80R22.5 and the wide-base wheel type is 425/65R22.5. Loading can be uni- or bi-directional, and lateral movement is 0.75 m. The wheel load is from 20 kN to 110 kN (corresponding to axle loads of 40...220 kN) at speeds up to 15 km/h. The number of loads is 25 000 in 24 hours (including daily maintenance).

The HVS-NORDIC is the only mobile APT facility in Europe and the only mobile APT facility in the world with full temperature control. The loading of the HVS-NORDIC can be varied dynamically +/- 20 %. As far as we know, there are no possibilities for dynamic loading in any other APT facility.

1.3. Test site

The test site was located on Ring Road II, which was under construction during the test period. The cross-section of motorway has two carriageways and two lanes in both directions. The distance was five kilometres from the office of VTT's personnel.

2. TEST PAVEMENTS

2.1. The aim of the tests

The aim of the tests was to study two different road structures for heavy traffic roads, a conventional road structure (test 09), and a new innovative one (test 10). The test structure 10 varies from the test 09 only by bound layers.

The research idea was that the lowest bound layer is conventional asphalt concrete, which has high resistance to fatigue but is not very stiff. This layer tolerates much more tension compared to conventional asphalt concrete in the base layer. Above this layer is an asphalt concrete binder course, which is made with Gilsonite and is very stiff, three times stiffer compared to conventional asphalt concrete. This layer spreads the traffic load and makes strains in the under-lying layers smaller. The resistance to fatigue is not so important in this material because it is located close to the neutral axle.

Test 09 is a reference structure for heavy trafficked roads in Southern Finland. The second SMA layer will be made usually after one or two years after opening a road to traffic. The road structures were built on hard rock, with the surface of the hard rock blasted to 700-mm depth. On blasted rock there is a 250 mm base course material which was made of crushed rock. The structure of test 09 is shown in Figure 2.

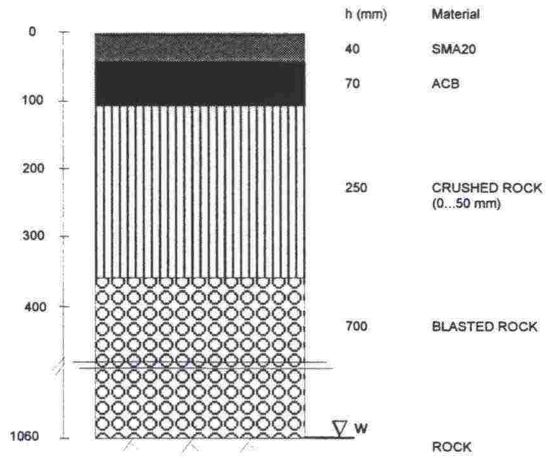

Figure 2.The structure of test 09.

Test 10 is so called innovative structure. The structure of test 10 differs from test 09 only by the bound layers. The research idea was that the lowest bound layer is conventional asphalt concrete, which has high resistance to fatigue but is not very stiff. On this layer, an asphalt concrete binder course with Gilsonite was made. This material is three times stiffer compared to conventional asphalt concrete. This layer spreads the traffic load and makes strains in the under-lying layers smaller. The structure of test 10 is shown in Figure 3.

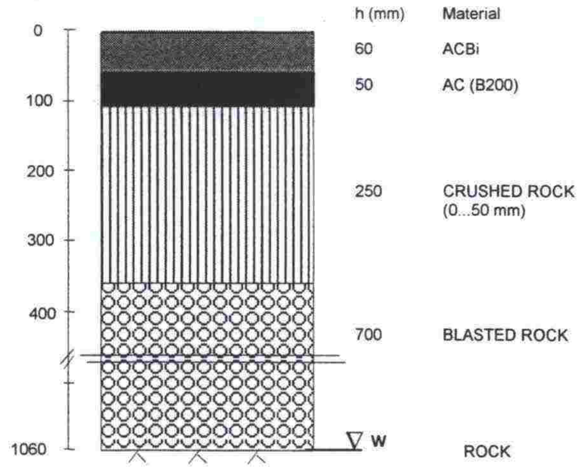

Figure 3. The structure of test 10.

2.2. Materials

The test structures were built on hard rock. The surface of the hard rock was blasted to a depth of 700 mm. On the blasted rock there was a 250 mm base course, which was made of crushed rock. On these unbound layers there were two bound layers, ACB+ SMA (test 09) and AC (B200)+ACBi (test10).

2.3. Laboratory tests of materials

The results of the base course material tests are shown in Table 1. The material is medium coarse-grained granite gneiss. The grading curve of the crushed rock is shown in Figure 4. The quality of the material is not good but it is the same for both structures and a comparison of different bound layers can be made.

Table 1. Results of base course material tests.

Density	2.68 kg/m^3
Los Angeles coefficient	36.1
Ball Mill value	21.6
Flakiness Index	11.6 %

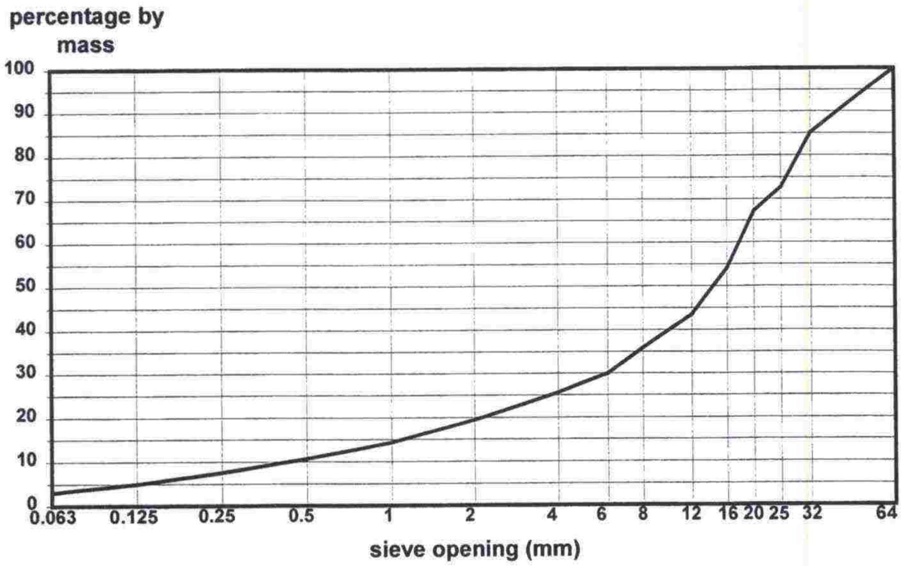

Figure 4. The grading curve of the crushed rock (base course material).

Four different bituminous layers were laid on the test sections. Generally, bitumen (B80) was used. In the conventional structure, typical materials were used – asphalt concrete in the base layer, ACB and SMA as a wearing course. In the innovative structure, (with high resistance to fatigue), asphalt concrete was made with softer bitumen (B200) and very stiff asphalt concrete in the binder course, ACBi was made with Gilsonite (17 % of bitumen material). The mixes were made according to Finnish Asphalt Specifications 2000 /3/.

The grading curves for the mineral aggregates of the bituminous layers are presented in Figure 5.

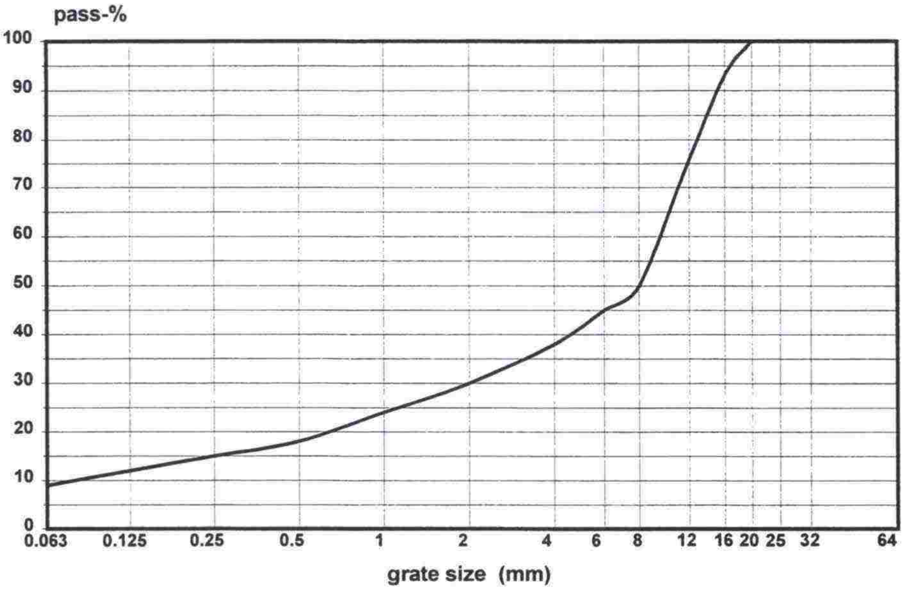

Figure 5. The grading curve of the mineral aggregates of the four bituminous materials.

The stiffness modulus (FAS-454) of the different bound layers are presented in Figure 6 and 7 in two different ways. The modulus of ACBi is much higher especially at high temperatures, and the modulus of AC (B200) is remarkably lower than that of the other materials.

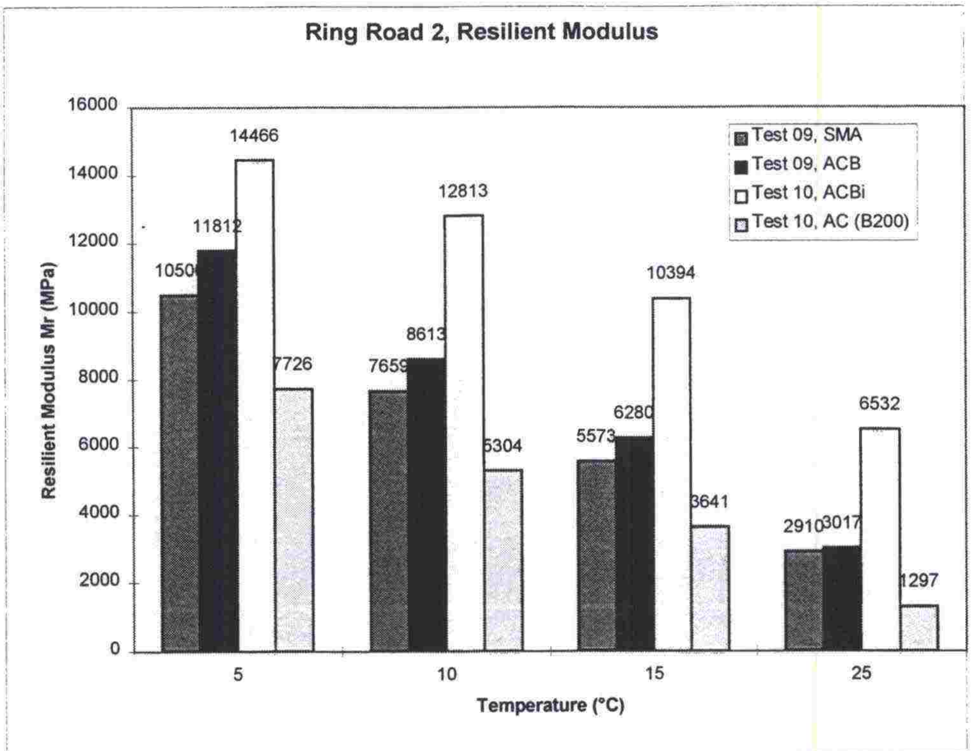

Figure 6. The stiffness modulus (FAS-454) of the different layers of test structures at four temperatures.

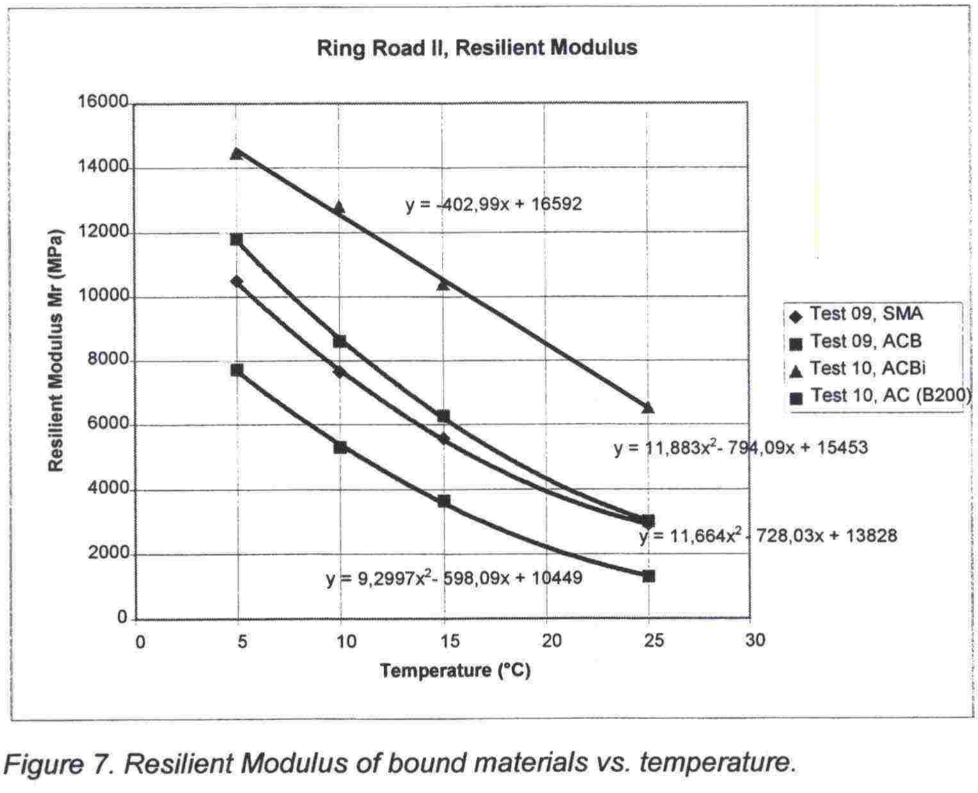

Figure 7. Resilient Modulus of bound materials vs. temperature.

The fatigue criteria for AC (B200) and ACB were determined in the laboratory for similar materials some years ago. These criteria are shown in Figure 8. It can be seen that, at the same strain level, AC (B200) can tolerate 100 times more load cycles than ACB (B80).

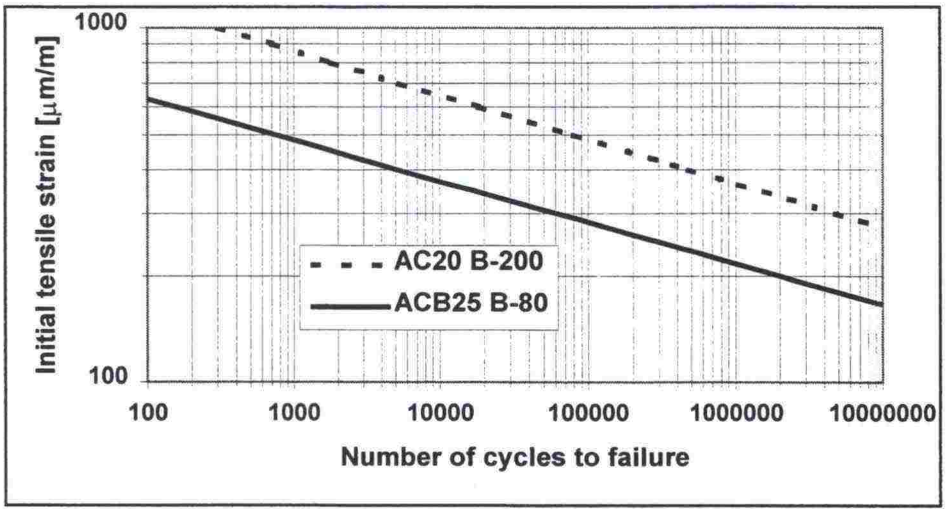

Figure 8. Fatigue criteria of AC20 (B-200) and ACB25 (B-80) /4, 5/.

2.4. Construction of tests, layer thickness

Tests 09 and 10 were made on Ring Road II in Espoo, 5 km from the office of VTT personnel.

The actual thickness of the bound layers were not similar to the planned structures. This made the comparison of the tests complicated. The actual thickness of the bound layers of tests 09 and 10 are shown in Figure 9 and Figure 10.

In test 09, the thickness of the ACB layer was on average 90 mm, which was 20 mm more than planned. The thickness of the SMA layer was on average 45 mm, which was 5 mm more than planned.

In test 10, the thickness of the AC (B200) layer was on average 50 mm, which was the same as planned. The thickness of the ACBi layer was on average 65 mm, which was 5 mm more than planned.

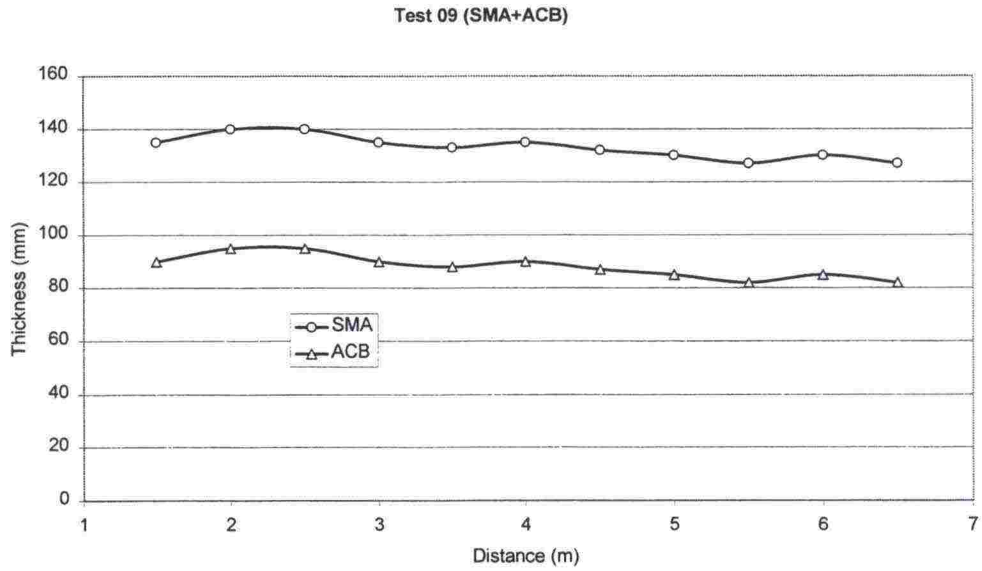

Figure 9. The actual thickness of the bound layers in test 09, conventional structure.

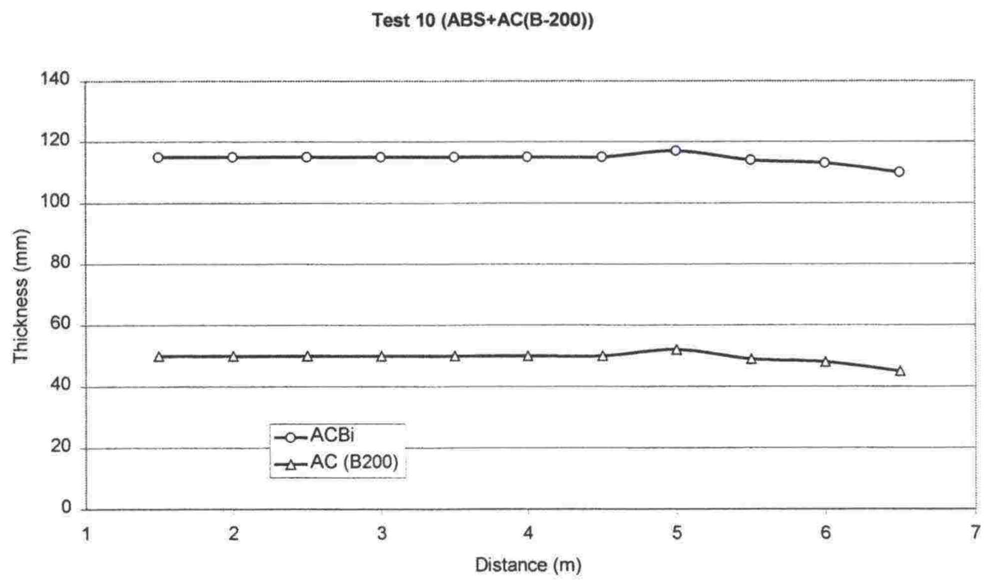

Figure 10. The actual thickness of the bound layers in test 10, innovative structure.

2.5. Instrumentation

The instrumentation for the response measurements was mainly based on the experience that has been gained at the Virttaa test site during the last 15 years.

The basic instrumentation is based on strain gauges installed at the bottom and on the surface of the bituminous layers. VTT uses retrofit strain gauges.

Five longitudinal and five transverse gauges were installed at the bottom of the bituminous layers, and three longitudinal and three transverse gauges on the surface of the asphalt layer.

Stress in the unbound layers was measured with stress sensors bought from the University of Nottingham. Five of these were installed at the same level, at a height in the middle of the base course.

Deflection under the moving wheel load was measured by a deflection rod that was anchored in the rock.

The position of the sensors is shown in Figure 11.

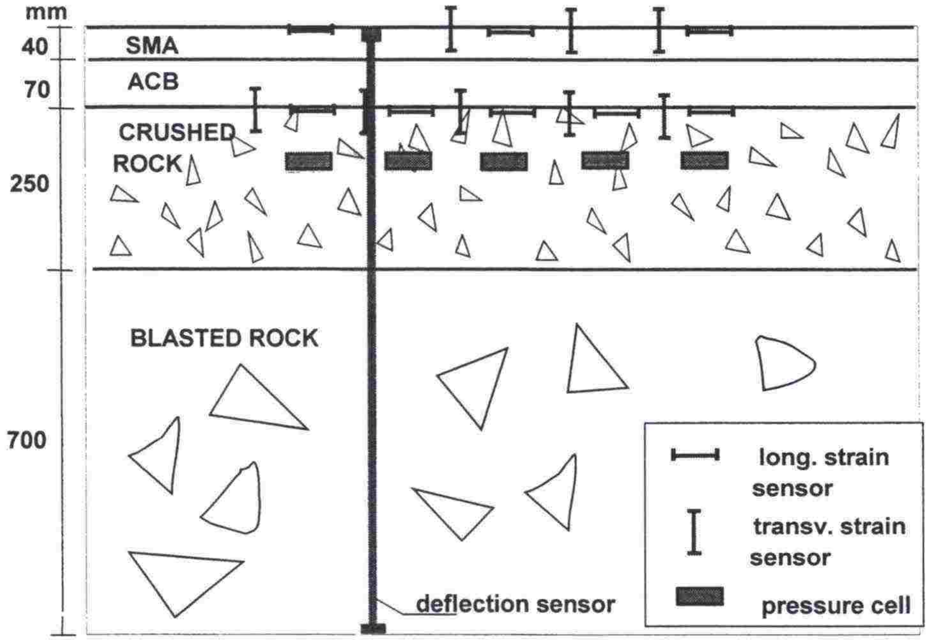

Figure 11. Instrumentation plan.

The temperature of the bituminous layers was measured at three depths: on the surface, in the middle and at the bottom of the bound layer.

2.6. Test procedure

The test procedure includes preloading, test parameters, initial response measurements, response measurements during testing, observations of rutting and cracking, post mortem sampling and testing.

In this case the number of load repetitions should be millions. Because of lack of time the number of loads of these tests were too few for pavement deterioration.

2.6.1. Preloading

The test was started first with a pre-run in order to relax possible residual stresses and to cause some post-compaction. This was done with a small wheel load: 30 kN single wheel load and 20 000 passes.

2.6.2. Test parameters

The standard temperature of bituminous materials for the tests was selected as +10°C, which is close to the weighted mean temperature in Southern Finland and Sweden. The loading mode was bi-directional. The standard dual wheel load was 60 kN and the tyre inflation pressure was 800 kPa. This corresponds to some overload and was selected to slightly accelerate the test. The speed was 12 km/h.

2.6.3. Initial response measurements

After the pre-run, initial response measurements were made, which included a considerable number of response measurements: strain, stress and deflection measurements at different wheel loads, tyre inflation pressures, lateral positions and temperatures. Both wide-base tyre and dual tyres were used. The measurement programme is presented in Appendix 1.

The response measurements were made at five temperatures: 0°, +5°, 10°, 15° and 20°C. The change in the temperature by five degrees took half a day.

Six wheel loads from 30 kN to 80 kN were used, and five tyre inflation pressures from 500 to 900 kPa were used for each wheel load.

The speeds were 1, 4, 7, 10 and 12 km/h. Two transverse positions were used for measurements with the dual wheel, with sensors under the tyres and between the tyres. For the single wheel, only one transverse position was used, with sensors under the tyre. The effect of transverse position was measured with one axle load and one tyre inflation pressure.

2.6.4. Response measurements during testing

The pavement responses due to a moving wheel load were measured during testing twice a week or more often. The measurements were made only with constant test parameters.

2.6.5. Observations, rutting and cracking

Rutting was observed visually every morning and if needed measured with a laser profilograph. In the beginning of the test and at least once a week, transverse profiles at five locations were measured with a laser profilograph.

Cracks were observed visually every morning.

2.6.6. Post mortem sampling and testing

When the test was completed, samples were taken from both the unbound and bound materials. Both loaded and unloaded areas were also sampled. The samples were tested in the laboratory according to the "basic minimum" program /6/.

3. MEASUREMENTS, OBSERVATIONS AND ANALYSIS

3.1. Measurements with falling weight deflectometer

Falling weight deflectometer (FWD) measurements were performed in four different phases. The first measurement was taken from the surface of the base course, before the asphalt layers. The second one was taken from the surface of the first asphalt layer. The third measurement was taken after the test site was ready, and the last measurement after the test was done. Deflections were measured at three load levels. These measurements cannot be made under the HVS machine.

The FWD deflections on the constructions of tests 09 and 10 are shown in Figure 12 and Figure 13.

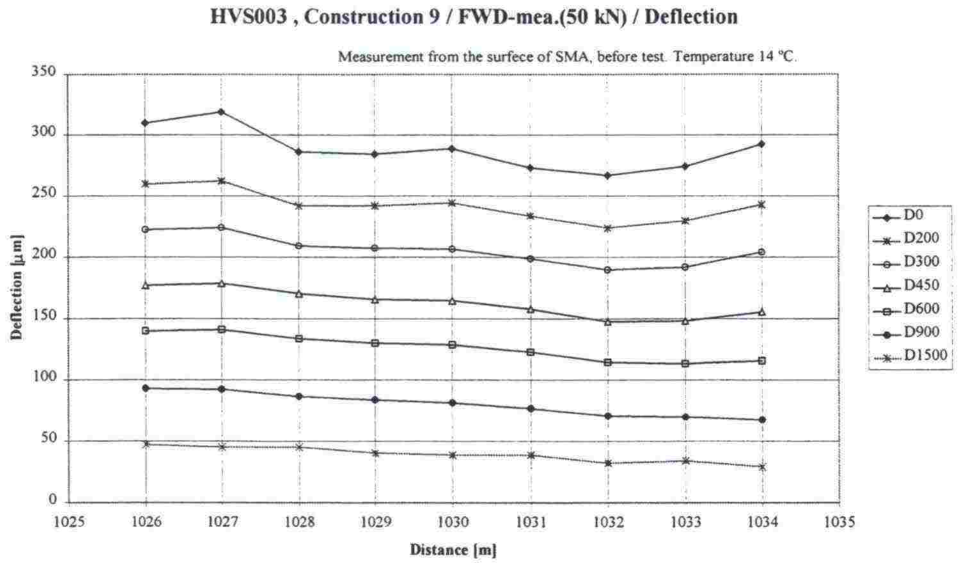

Figure 12. Deflection values of test 09, conventional structure.

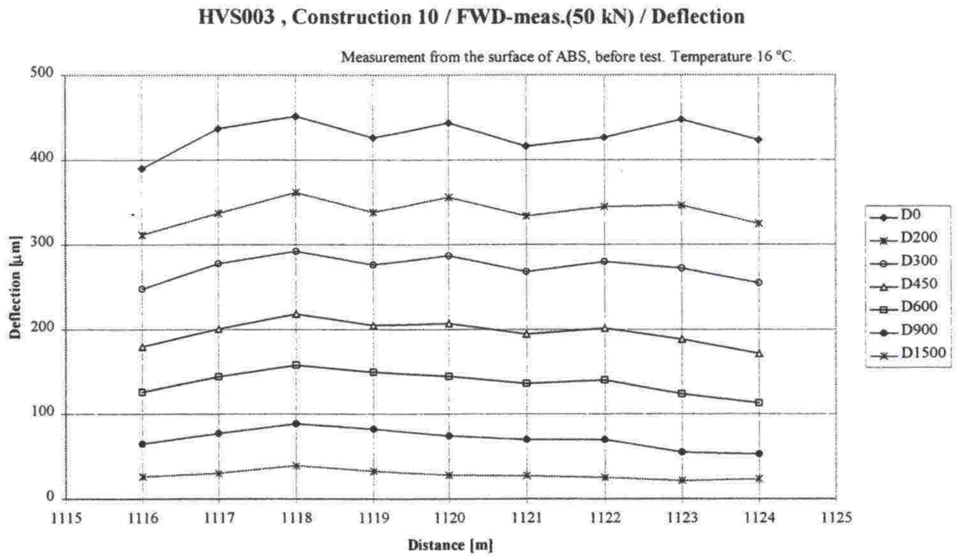

Figure 13. Deflection values of test 10, innovative structure.

According to the FWD measurements, the conventional structure is stronger than the innovative one. However, it must be also stated that the bound layers of the conventional structure are 20 mm thicker.

The back calculation of the moduli of the pavement materials is presented in Table 2. The back calculation was made with the Modcomp 3 program, which is based on the linear elastic multilayer theory.

The first row of each case is the result of the free modulus calculation. The results are unreasonable and therefore the calculations have been made with the fixed bound material modulus. The fixed values are chosen based on the stiffness modulus tested in the laboratory and on the measuring pavement temperature. With fixed values (*) the calculated moduli are more reasonable.

Table 2. The results of back calculation. (* = fixed value)

Test 09 (Resilient Modulus, Modcomp3 program)					Temp 14 °C
(Distance)	SMA20	ACB	Base course	Subbase	Bedrock
1026	251000	606	359	67	*3500
	*6000	*6800	742	65	*3500
1030	1660	25200	507	79	*3500
	*6000	*6800	891	70	*3500
1034	145000	1260	512	84	*3500
	*6000	*6800	694	87	*3500

Test 10 (Resilient Modulus, Modcomp3 program)					
					Temp 14 °C
(Distance)	ACBi	AC	Base course	Subbase	Bedrock
1026	42900	1730	420	114	*3500
	*10900	'3900	694	107	*3500
1030	15600	2710	541	70	*3500
	*10900	*3900	560	70	*3500
1034	3900	19300	244	103	*3500
	*10900	*3900	328	95	*3500

3.2. Measurements with benkelman beam

Deflections due to different wheel loads were measured during the test with a benkelman beam at three locations. The tests were quite short term and the deflections were measured once during test 09 and twice during test 10. In both tests, the measurements were done after the initial measurements and in test 10 also after 470 000 passes.

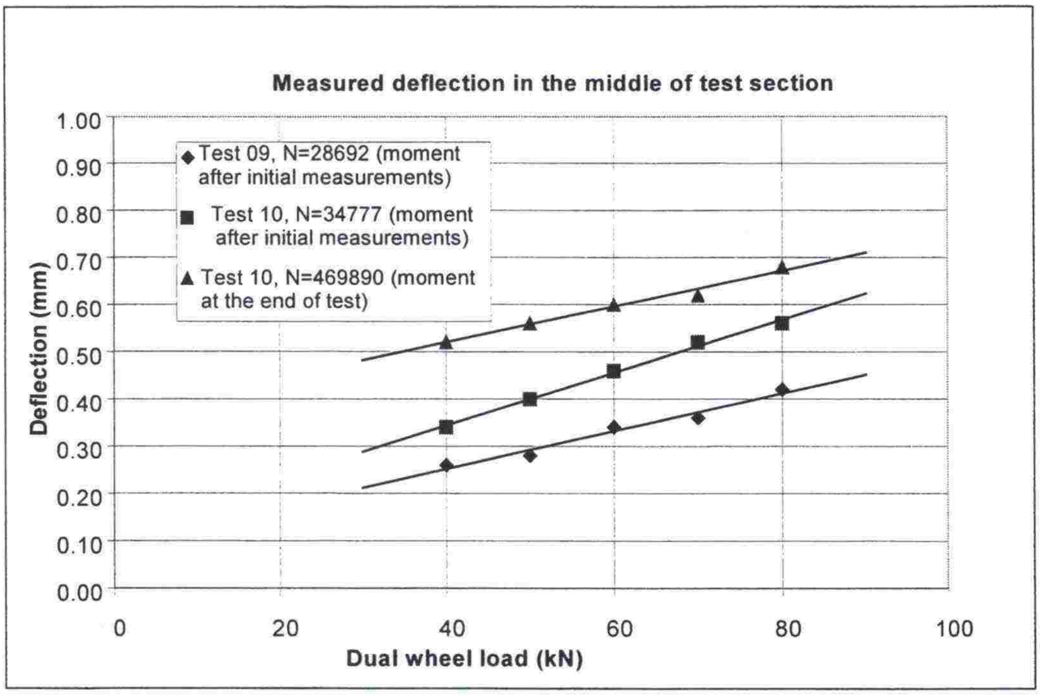

Figure 14. Benkelman beam measurements of test 09 (conventional structure) and test 10 (innovative structure).

According to the benkelman beam measurements, the conventional structure is stronger than the innovative one. The situation is similar to the FWD measurements; both are based on deflection.

After 440 000 passes of a 60 kN wheel load, the deflection increased in test 10. The reason could be the deterioration of the unbound base course or initial cracking at the bottom of the bituminous layers.

3.3. Response due to HVS wheel load

3.3.1. Initial response measurements

Initial response measurements were made after the pre-run before the actual test loading. A huge number of different parameter combinations were used in the measurements (Appendix 1).

Typical signals of different responses, stress, strain and deflection due to moving wheel are presented in Figure 15-18.

The soil pressure cell measures the vertical component of stress even though the horizontal component may have some minor indirect effect. The signal is symmetric, as can be seen in Figure 15.

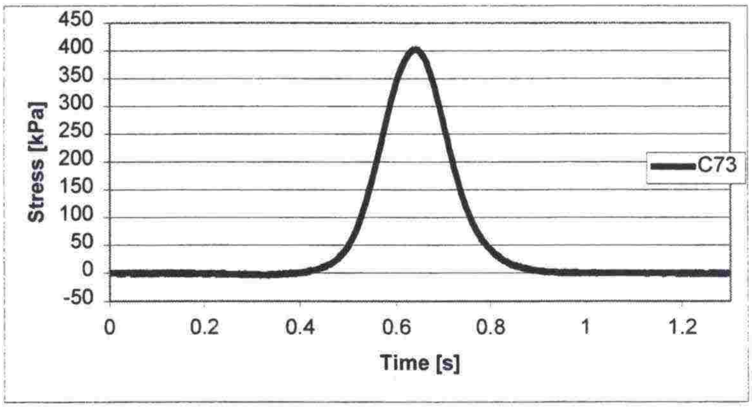

Figure 15. Typical signal of the soil pressure cell.

As the wheel of a vehicle approaches a sensor, the bituminous layer bends and causes compression at the bottom of the bituminous layer, as can be seen in Figure 16 (strain is negative). As the wheel is on the sensor, the strain at the bottom of the bituminous layer measures the tensile or positive value. Typically compression is about one third of tension in the initial stage, depending on the pavement temperature, AC modulus, etc. After the wheel has passed the sensor there is once again compression, which is, however, smaller than the first compressive strain. It may be in certain cases nearly non-existent. However, the strain will always be of the same level (or zero) after the wheel has passed the sensor.

The basic shape of the longitudinal signal is the same even if a wheel does not overpass the sensor; the peaks are only smaller.

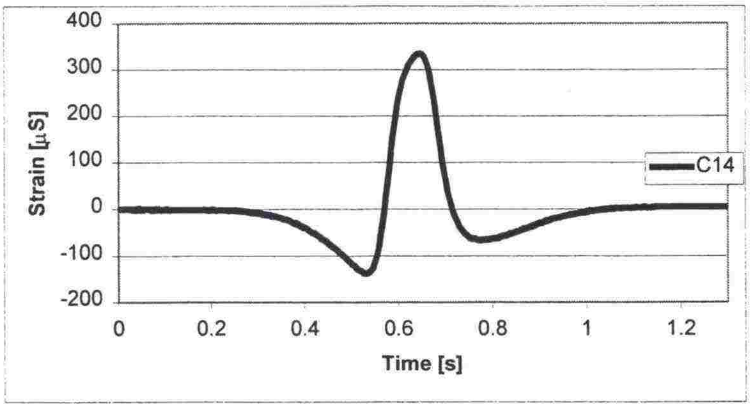

Figure 16. Typical signal of the longitudinal strain gauge at the bottom of bituminous layers.

As the wheel passes the transverse sensor, the strain at the bottom is tensile all the time, as can be seen in Figure 17. The signal is not symmetric but because of visco-elastic nature of the bituminous materials, stresses relax at a speed that is dependant on the temperature and the properties of the bituminous layers. The relaxation may take a long time and if the next wheel comes before relaxation has occurred there may be an accumulation of strains. This phenomenon is dealt with in reference 7 and 8.

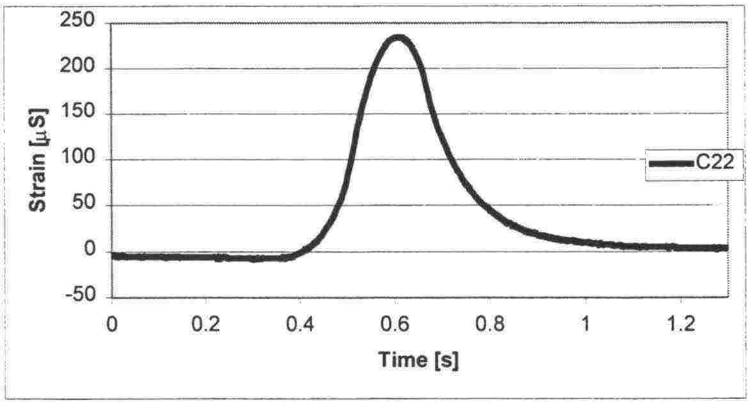

Figure 17. Typical signal of the transverse strain gauge at the bottom of bituminous layers.

Transverse strains are very sensitive to the lateral position of the wheel. They are tensile under the tyre but immediately outside the tyre imprint they are compressive. If there are several axles the shape of the signal may be very complicated because of the accumulation.

Deflection of the whole pavement is measured with a sensor attached to a steel rod going through the pavement down to the bottom of the test pit. The signal is not symmetric, as can be seen in Figure 18.

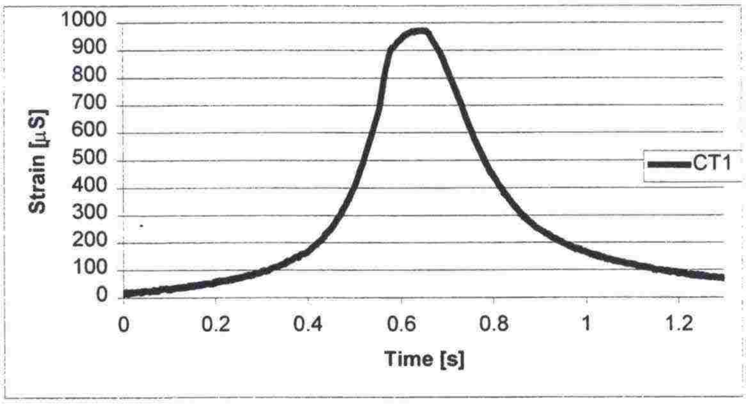

Figure 18. Typical signal of the deflection strain gauge.

The zero of the signals is taken about 0.6 seconds before the loading and thus no permanent strains or stresses are measured. The peaks are measured automatically and only a few signals are viewed.

However, seeing a signal may reveal something about the condition of the sensor or pavement. For instance, cracking close to the sensor can be found by comparing the actual strain signal at the bottom of the bituminous layers to that measured in the initial stage. Generally, comparing signals in different stages of testing is an important part of analysis

Generally in this test, pavement responses due to wheel load were higher in the innovative structure compared to the conventional one. The main reason for this was the thicker bituminous layers.

Figure 19 - Figure 22 show the effect of tyre pressure and wheel load on measured longitudinal strain at the bottom of the bituminous layers. The effect of wheel load is noticeable but the effect of tyre pressure is not so much.

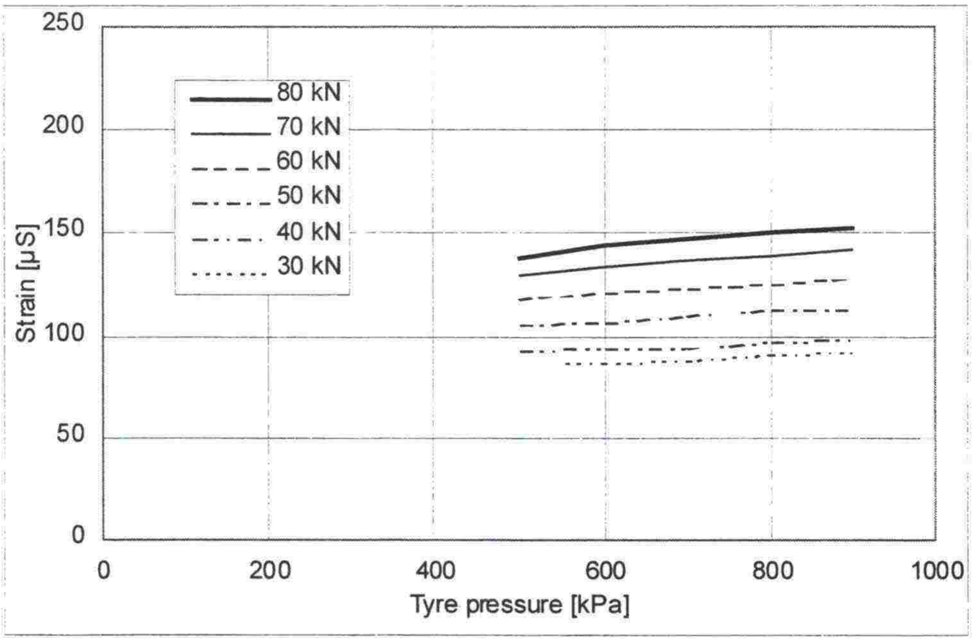

Figure 19. Measured longitudinal strain at the bottom of bituminous layers vs. tyre pressure with twin tyre in conventional structure (test 09).

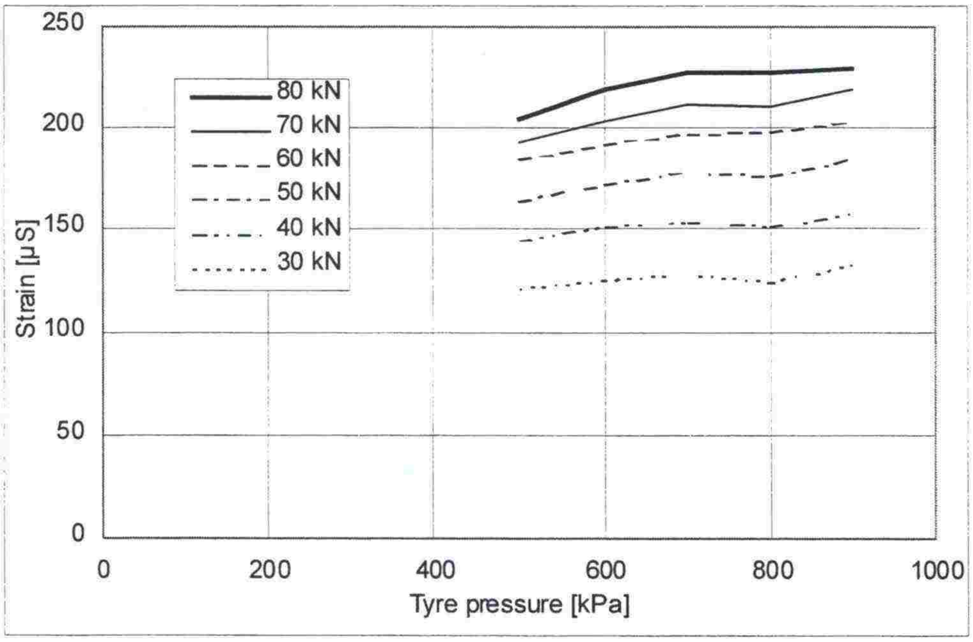

Figure 20. Measured longitudinal strain at the bottom of bituminous layer vs. tyre pressure with twin tyre in innovative structure (test 10).

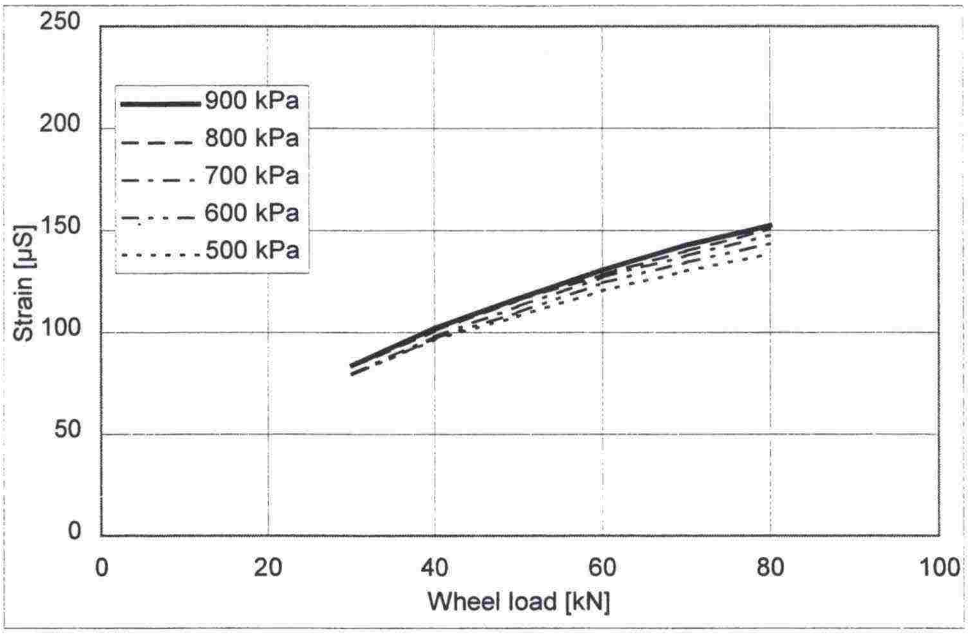

Figure 21. Measured longitudinal strain at the bottom of bituminous layer vs. wheel load with twin tyre in conventional structure (test 09).

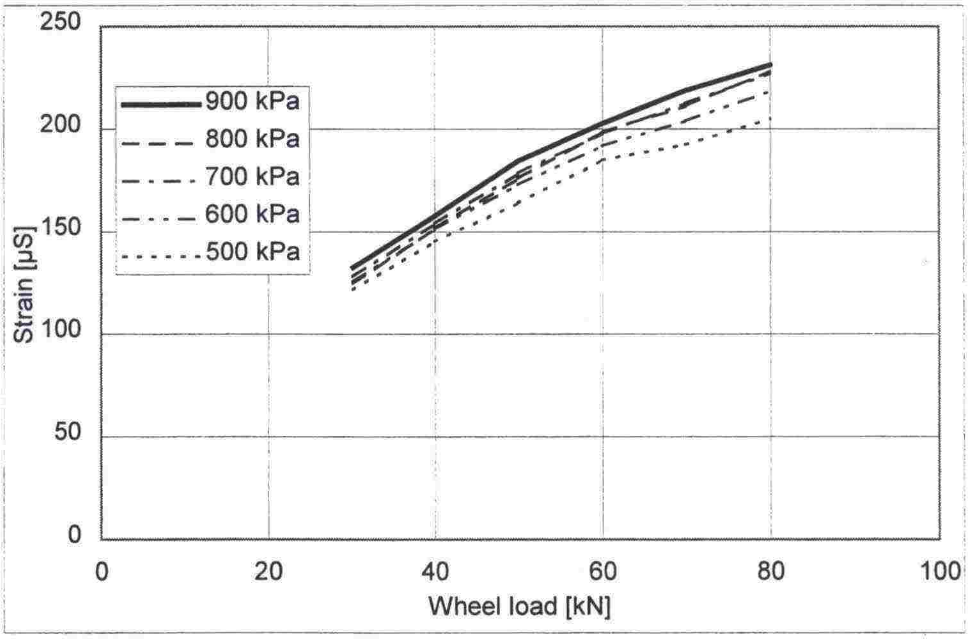

Figure 22. Measured longitudinal strain at the bottom of bituminous layer vs. wheel load with twin tyre in innovative structure (test 10).

Figure 23 and Figure 24 shows the effect of pavement temperature on the measured longitudinal strain at the bottom of the bituminous layers for different wheel loads. The effect of pavement temperature on asphalt strains is very large, which is why it is important to keep the temperature stable during testing for the comparison of different pavements.

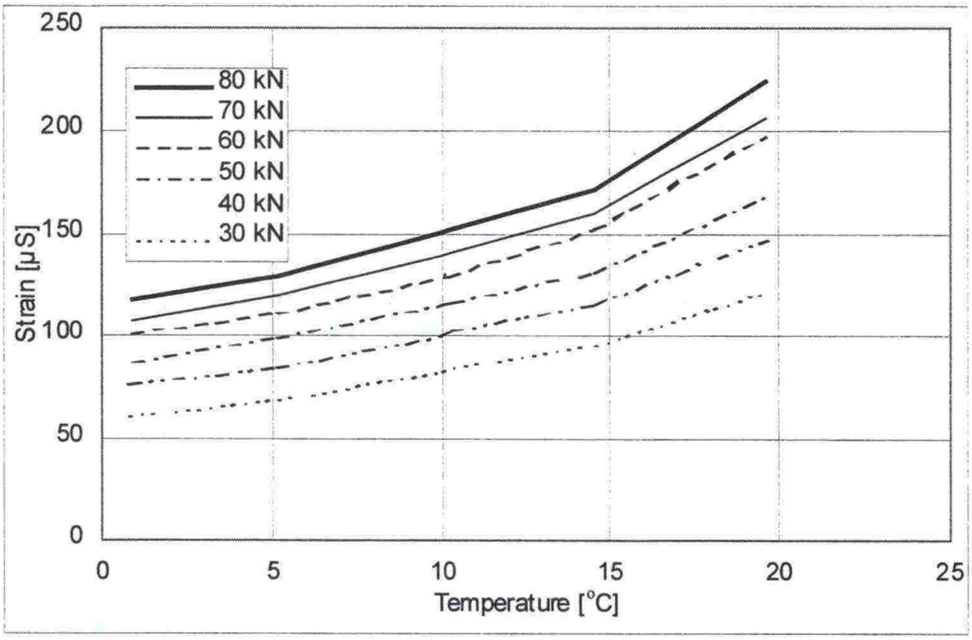

Figure 23. Measured longitudinal strain at the bottom of bituminous layer vs. temperature with twin tyre in conventional structure (test 09).

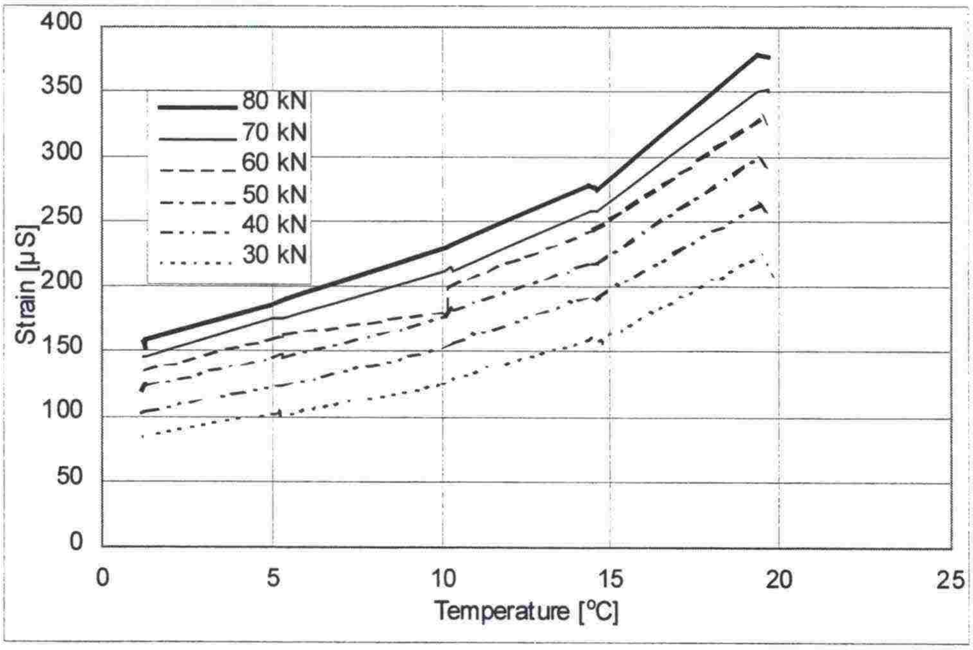

Figure 24. Measured longitudinal strain at the bottom of bituminous layer vs. temperature with twin tyre in innovative structure (test 10).

Longitudinal strain at the bottom of the bituminous layer vs. speed of test wheel is shown in Figure 25 and Figure 26. At low speeds the strains are much higher because of the visco-elastic nature of asphalt. In this speed range, the dependence between speed and longitudinal strain seems to be similar for both test wheels.

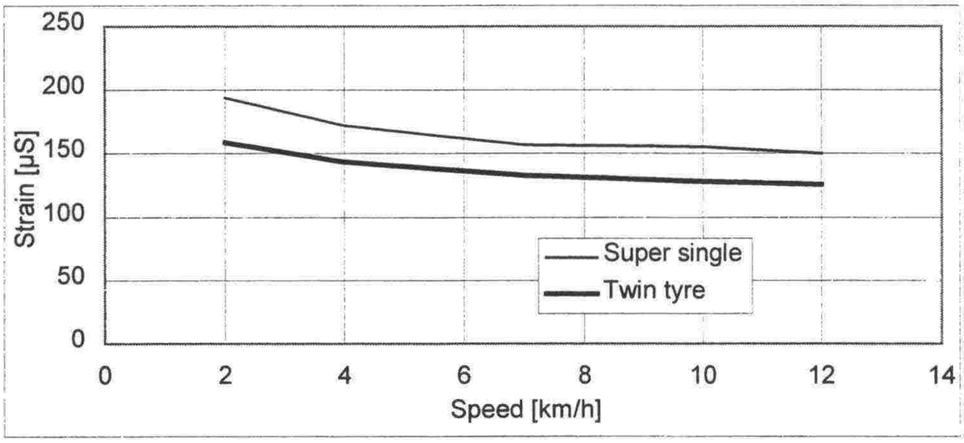

Figure 25. Measured longitudinal strain at the bottom of bituminous layer vs. speed with twin and single tyre in conventional structure (test 09).

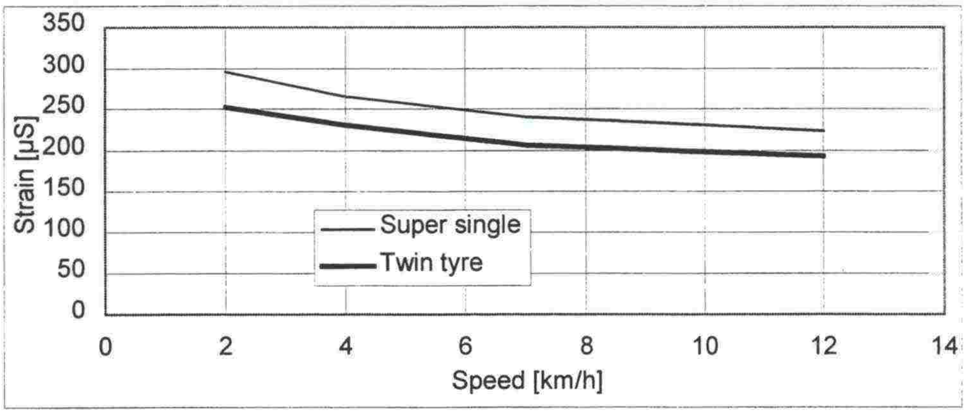

Figure 26. Measured longitudinal strain at the bottom of bituminous layer vs. speed with twin tyre in innovative structure (test 10).

The relation between wheel load and longitudinal strain at the bottom of the bituminous layers is shown in Figure 27 and 28. The measurements show that strain caused by a super single tyre is about 20 % higher than that caused by a twin tyre (800 kPa). The effect of tyre pressure is much higher with a single wheel.

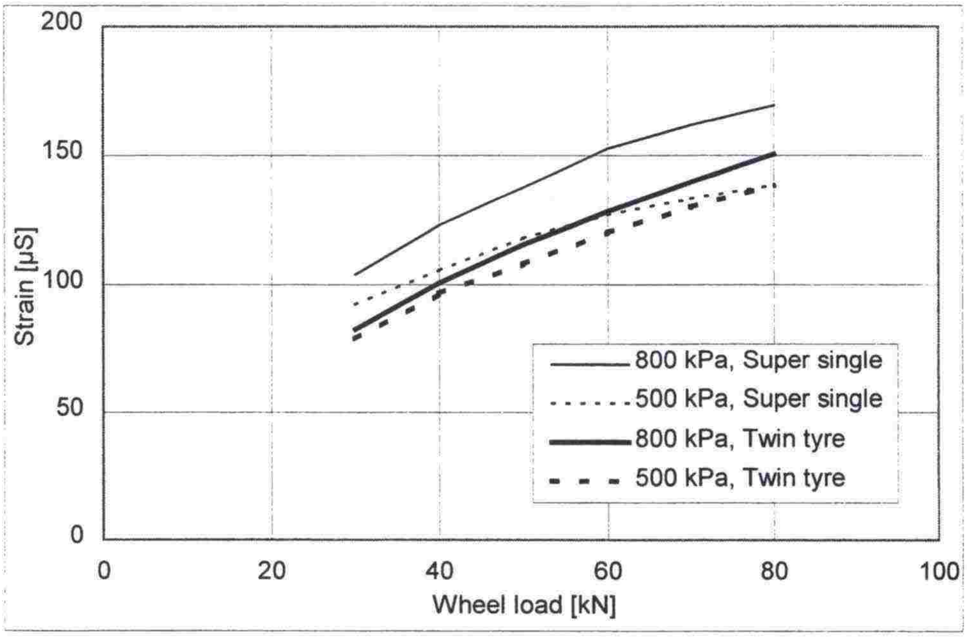

Figure 27. Measured longitudinal strain at the bottom of bituminous layer vs. wheel load with twin and single tyre in conventional structure (test 09).

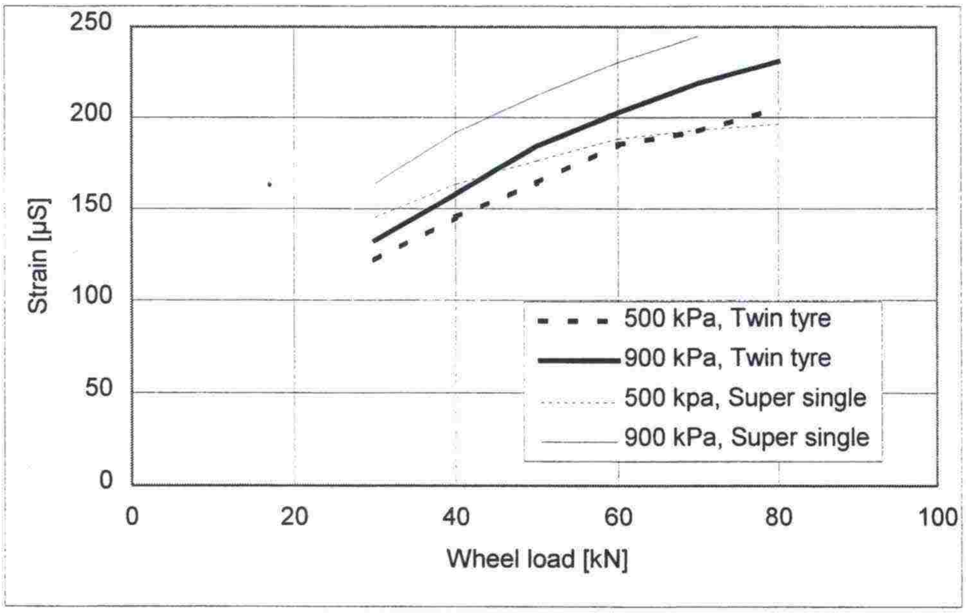

Figure 28. Measured longitudinal strain at the bottom of bituminous layer vs. wheel load with twin and single tyre in innovative structure (test 10).

The effect of wheel load on pavement surface strain is presented in Figure 29 and 30. The strain is compression but similar to that measured at the bottom of the bituminous layers.

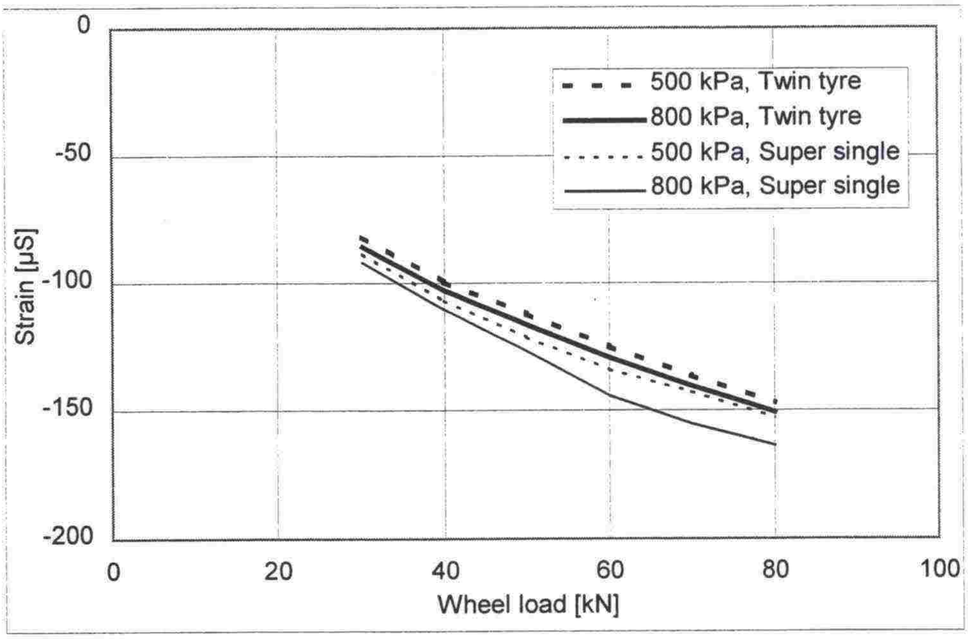

Figure 29. Measured longitudinal strain on the surface of bituminous layer vs. wheel load with twin and single tyre in conventional structure (test 09).

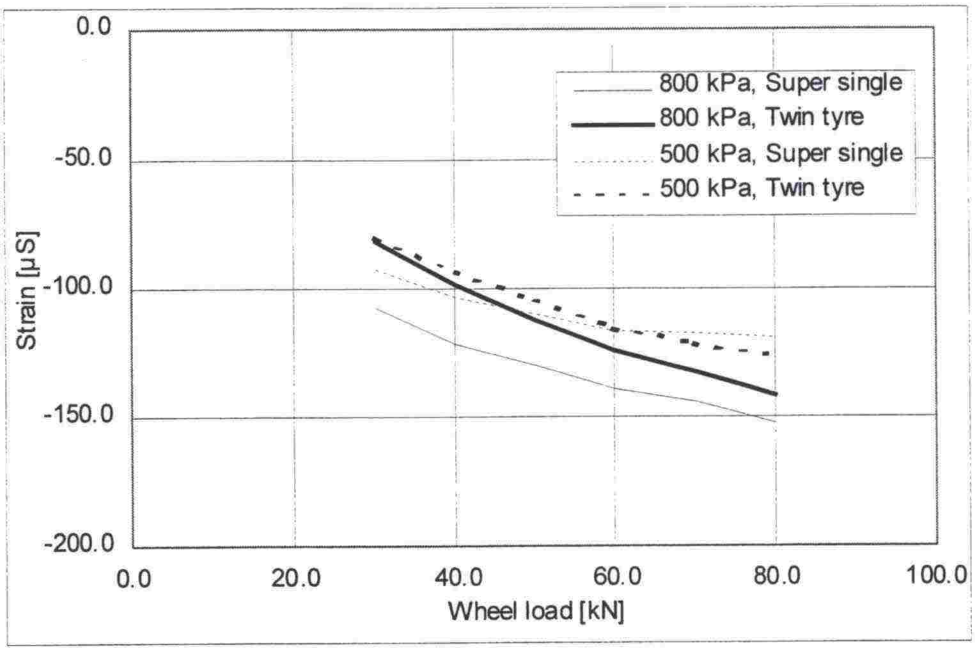

Figure 30. Measured longitudinal strain on the surface of bituminous layer vs. wheel load with twin and single tyre in innovative structure (test 10).

Comparison between longitudinal and transverse strain is presented Figure 31 and 32. Both strains are at the same level.

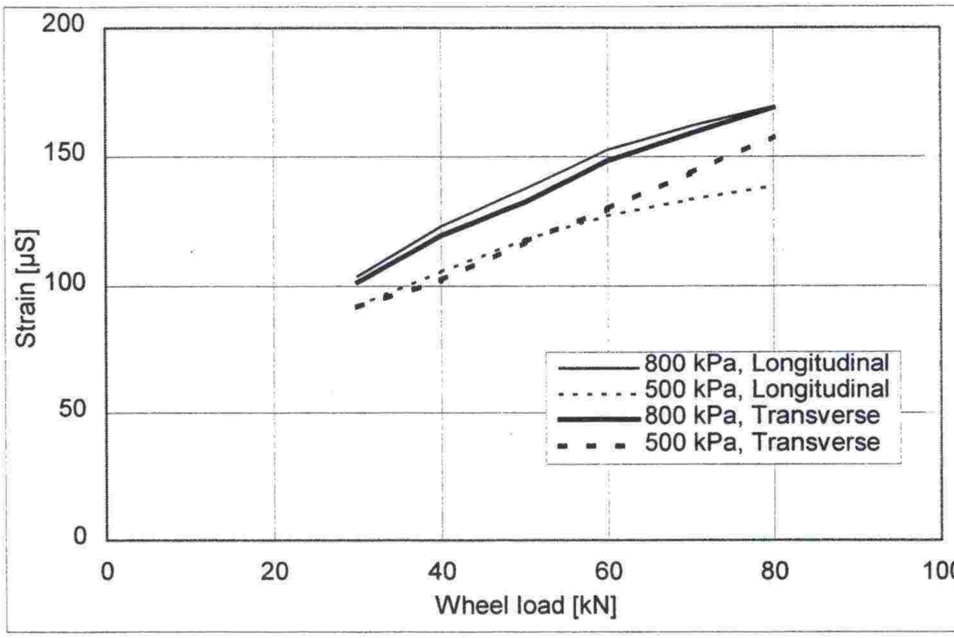

Figure 31. Measured longitudinal and transverse strain at the bottom of bituminous layer vs. wheel load with super single in conventional structure (test 09).

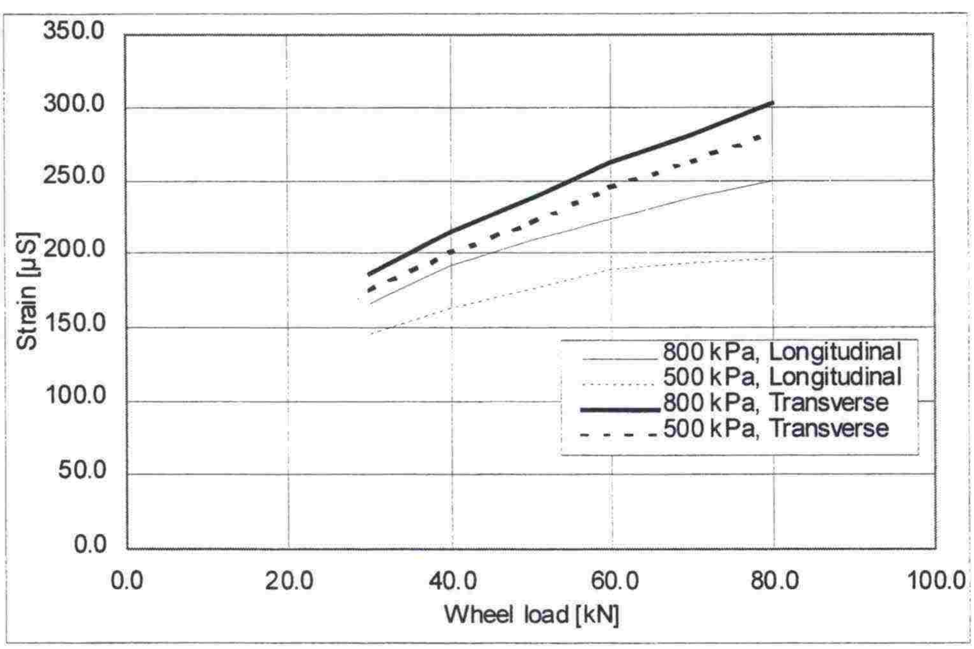

Figure 32. Measured longitudinal and transverse strain at the bottom of bituminous layer vs. wheel load with super single in innovative structure (test 10).

3.3.2. Response during testing

The pavement response due to HVS wheel load was measured during testing only with test parameters, which were 60 kN dual wheel load, tyre pressure 800 kPa and speed 12 km/h at 10 °C pavement temperature. The different responses, strain, stress and deflection vs. number of loads are presented in Figures 33 - 39.

The measured longitudinal strain at the bottom of the bituminous layers is presented in Figure 33. It can be seen that in most cases the strain decreases when the number of loads increase. That indicates initial transverse cracking at the bottom of the bituminous layers close to the strain sensor. This is evaluated according to Figure 34 which shows how compression is always at the same level but tension decreases when the number of loads increase, indicating initial cracking close to the strain sensor.

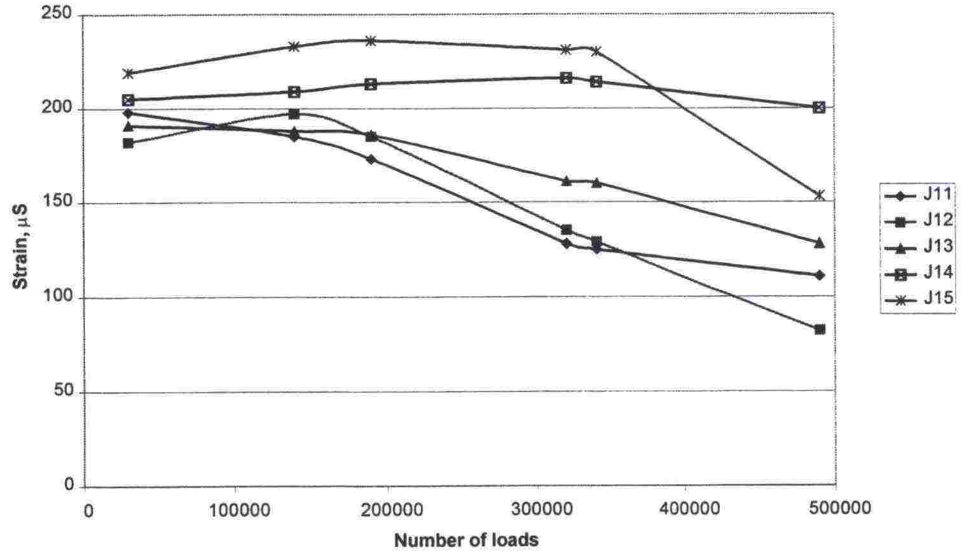

Figure 33. Longitudinal strain at the bottom of bituminous layers vs. number of loads in innovative structure (test 10).

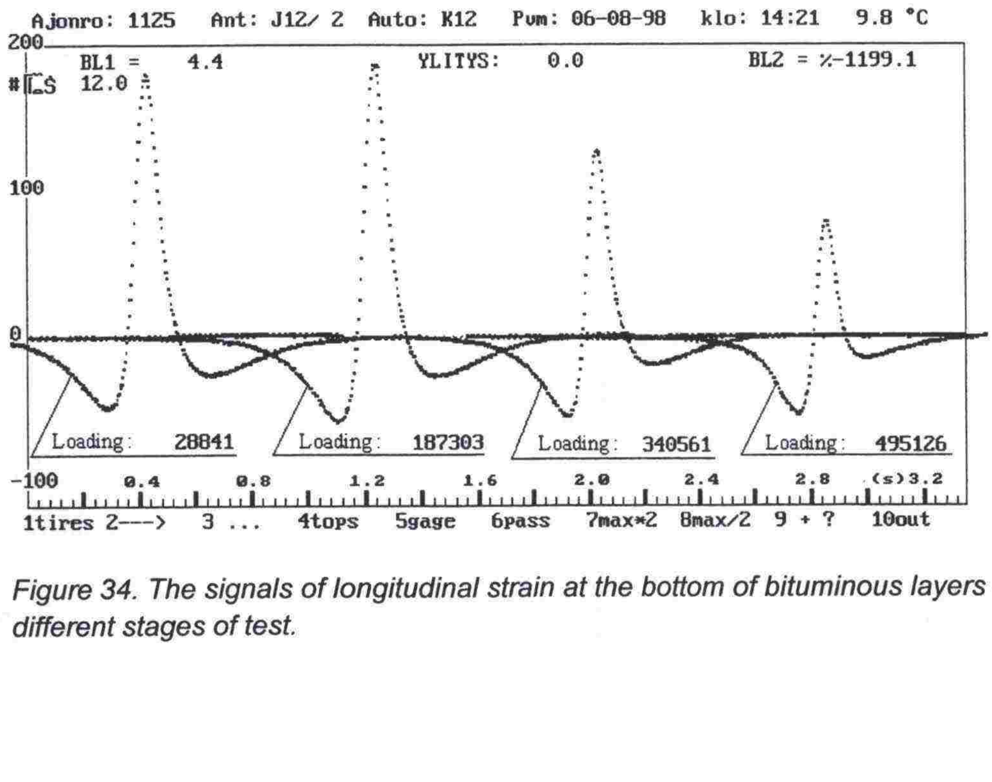

Figure 34. The signals of longitudinal strain at the bottom of bituminous layers at different stages of test.

Transverse strain is almost stable during testing, which indicates that there is an initial longitudinal crack close to only one strain sensor J22 (Figure 35).

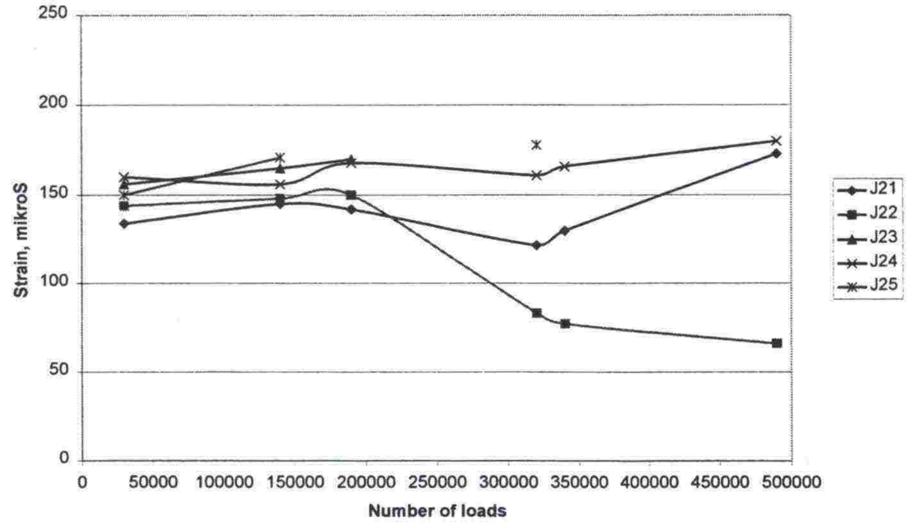

Figure 35. Transverse strain at the bottom of bituminous layers vs. number of loads.

The longitudinal strain on the pavement surface is almost stable during testing, indicating that there is no cracking. This is because possible hair crack on the surface of pavement transfers compressive strain (Figure 36). The transverse strain on the pavement surface is almost stable during testing, except on gage J07 indicating deterioration in pavement (Figure 37).

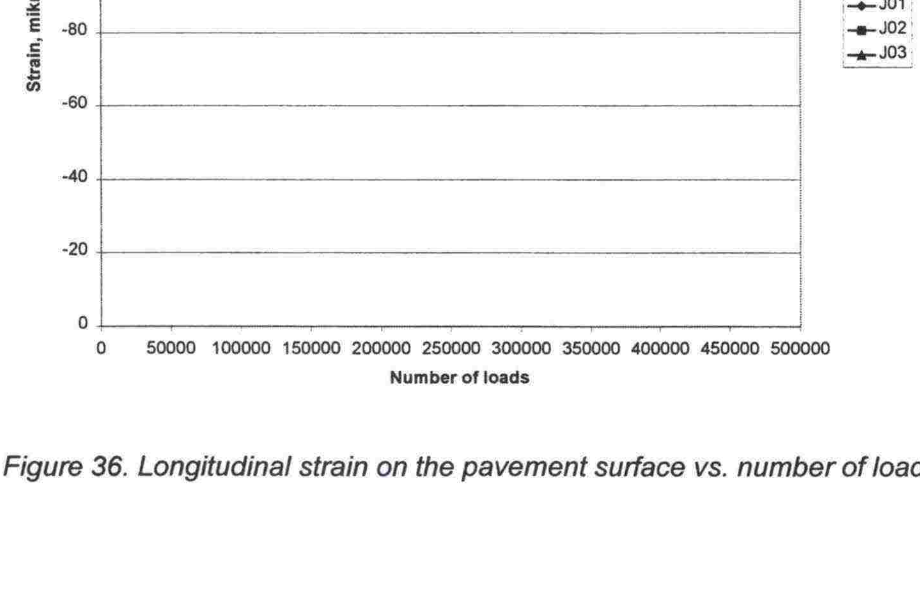

Figure 36. Longitudinal strain on the pavement surface vs. number of loads.

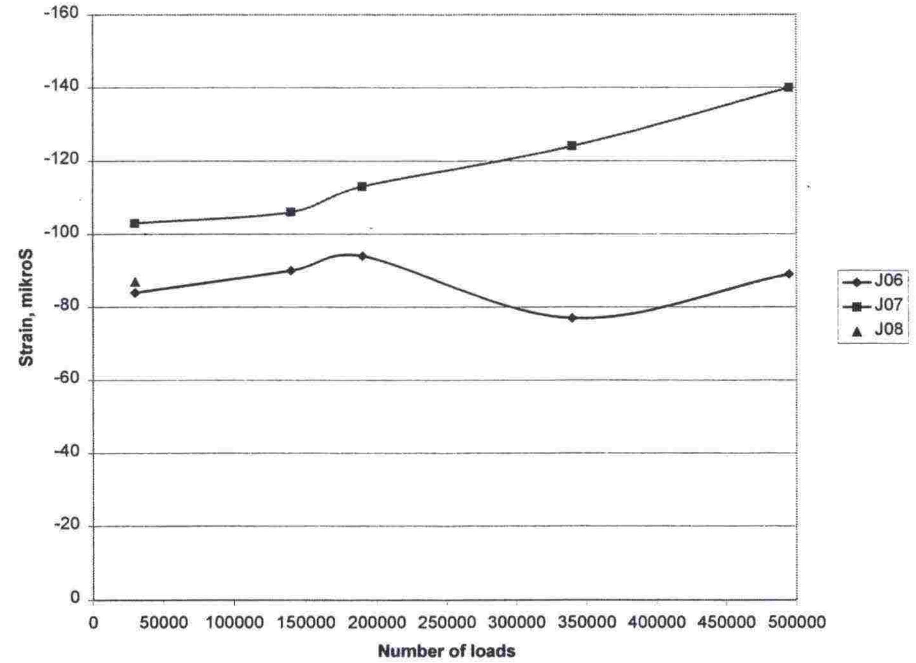

Figure 37. Transverse strain on the pavement surface vs. number of loads.

The stress in the unbound base layer is presented in Figure 38. Close to one gauge there is an increase in stress, indicating the deterioration of the structure.

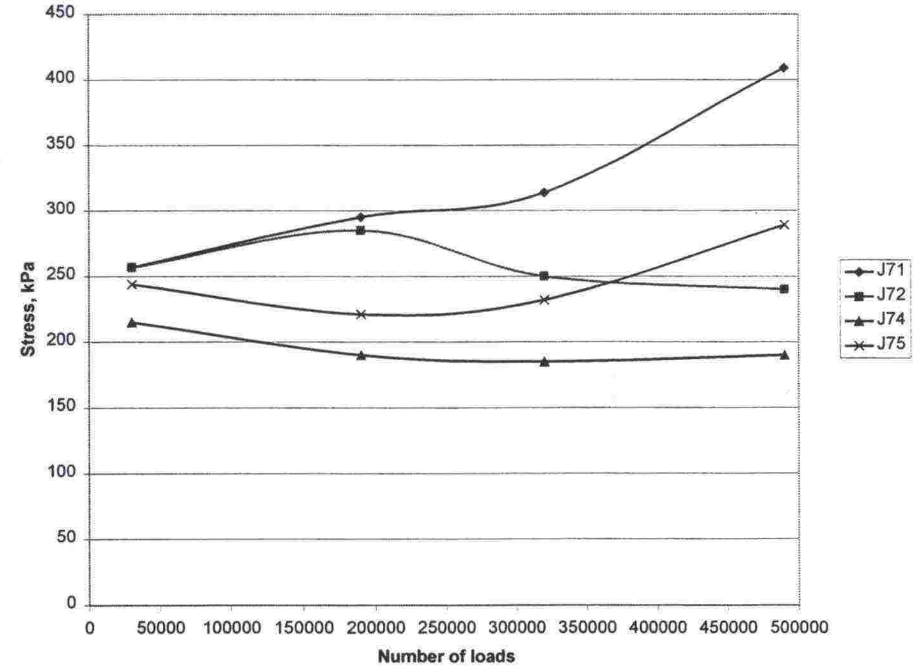

Figure 38. Stress in base course vs. number of loads.

The measured pavement deflection (Figure 39) is similar to the deflection measured with benkelman beam.

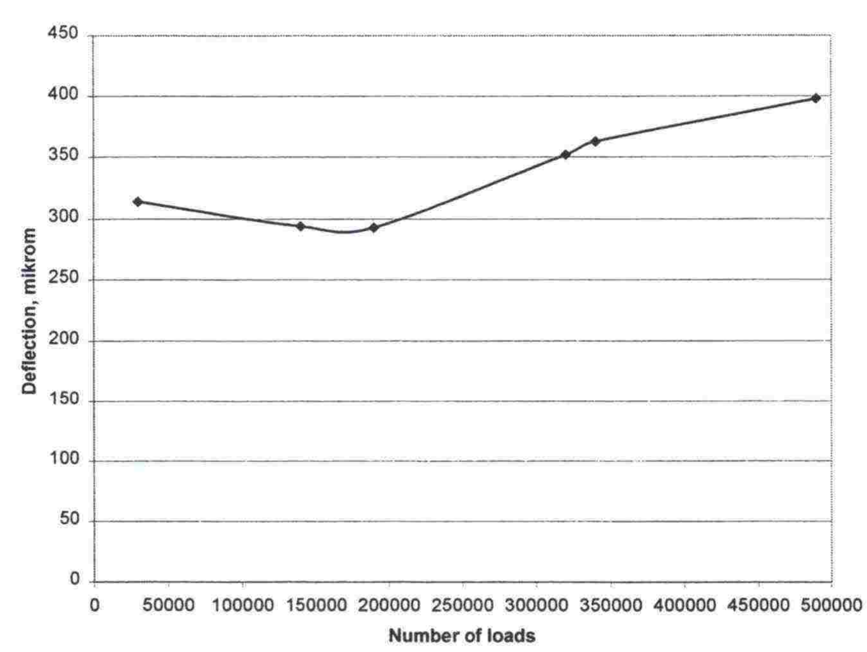

Figure 39. Pavement deflection vs. number of loads.

3.4. Testing after loading

After loading the HVS was removed from the test sections and FWD measurements were made on both sections. The results are presented in Figure 40 and Figure 41. The deflections increased only slightly in conventional structure (test 09) but in innovative structure (test 10) deflections decreased slightly, maybe because of compaction caused by HVS repeating loads.

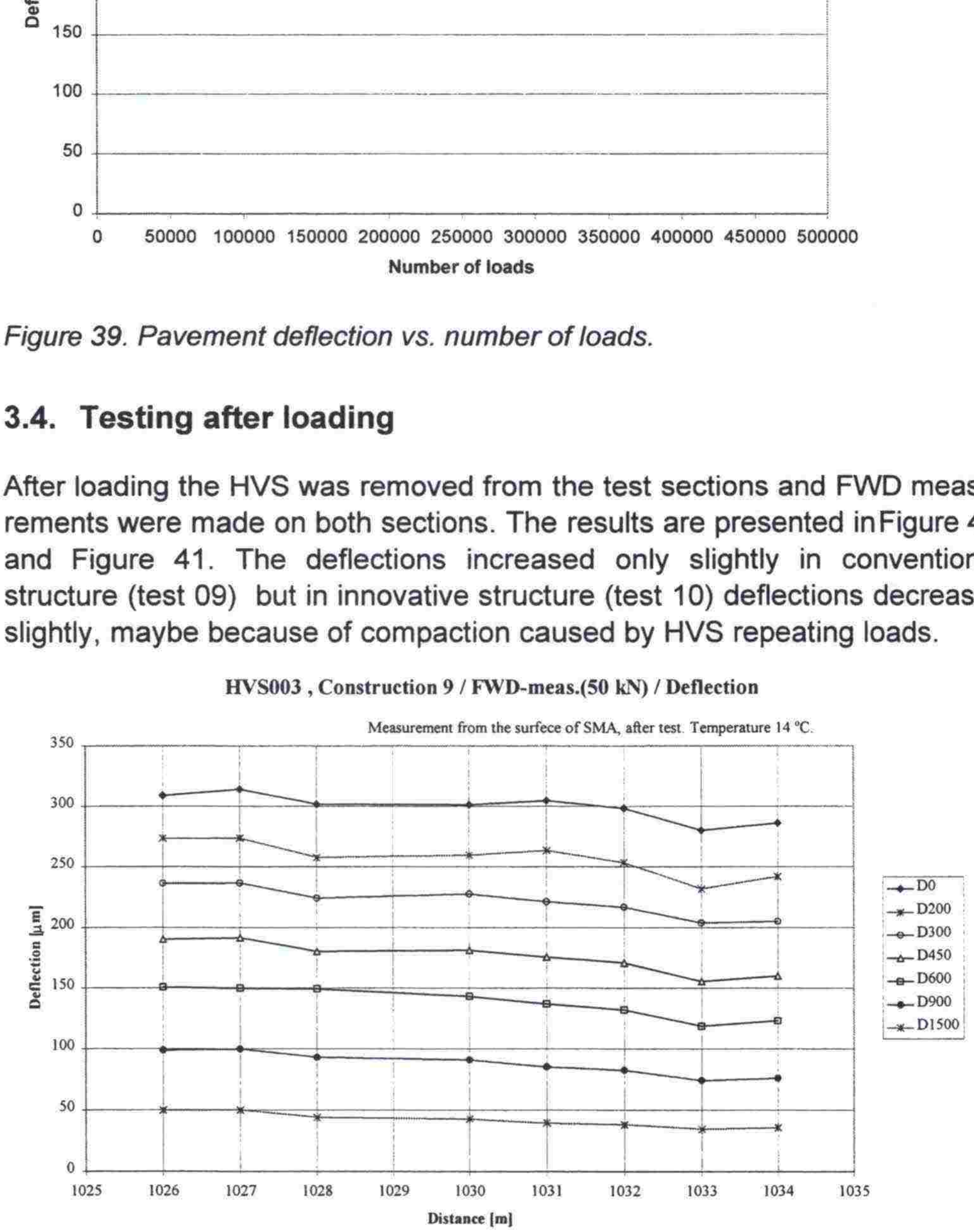

Figure 40. Measured FWD deflections after loading in conventional structure (test 09).

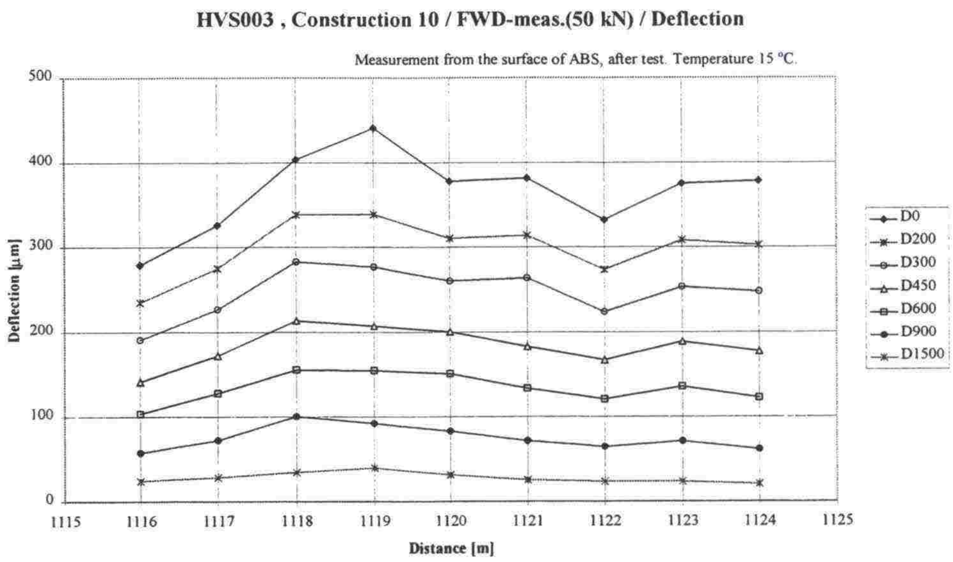

Figure 41. Measured FWD deflections after loading in innovative structure (test 10).

The grading curves of the base course material in the post mortem stage are presented in Figure 42 and Figure 43. Loading caused breaking and grinding in base course materials as can be seen in Figures.

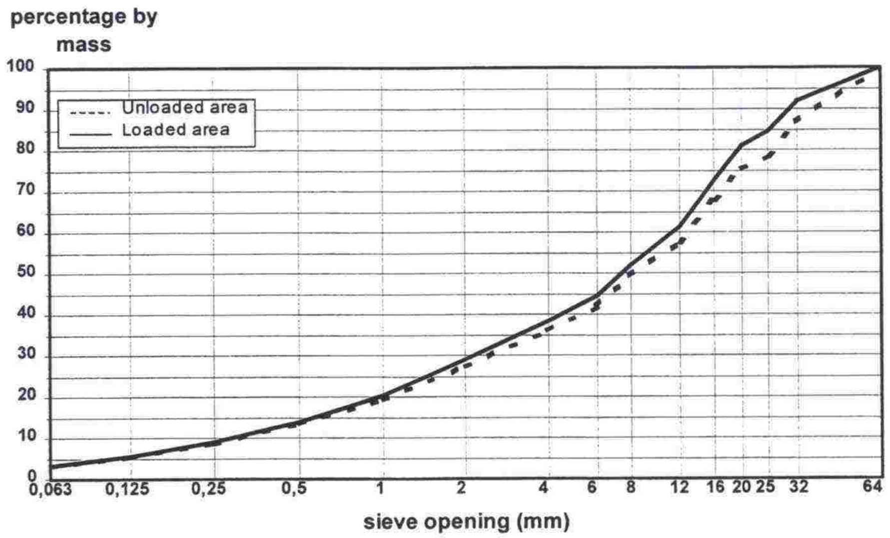

Figure 42. Grading curves of base course material in post mortem stage in conventional structure (test 09).

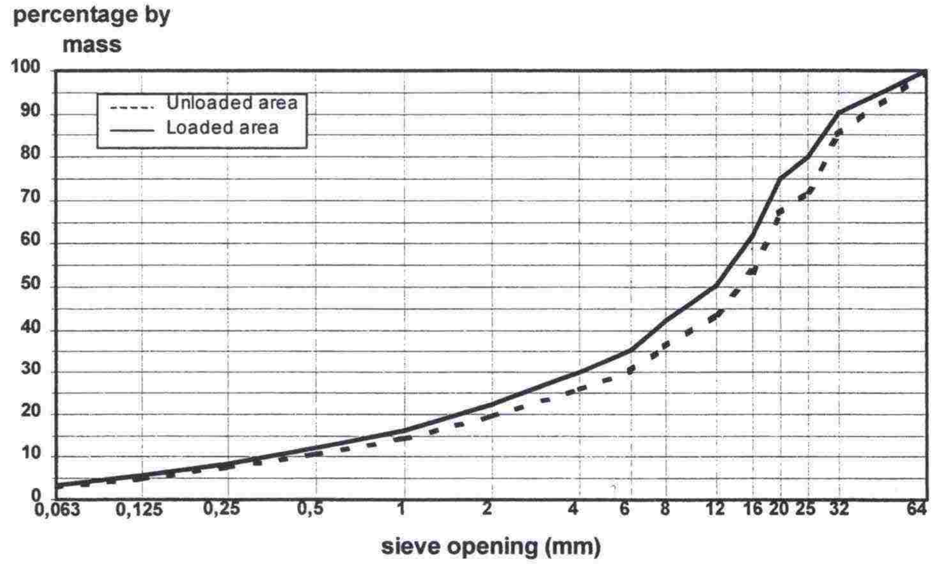

Figure 43. Grading curves of base course material in post mortem stage in innovative structure (test 10).

4. DISCUSSION

4.1. Comparison of test pavements

4.1.1. Rutting

After initial response measurements only 0.14 million loads were made on test 09 because of the HVS chain was broken. Very little rutting could be seen on the road surface and naturally there were no cracks.

After initial response measurements only 0.50 million loads were made on test 10. Less than 4 mm rutting could be seen on the road surface and naturally no cracks. These tests were interrupted because the HVS was transported to Sweden for the VTI tests.

Rutting for both tests is presented in Figure 44. After the initial response measurements, only 0.12 million loads on test 09 and 0.5 million loads on test 10 were made. In test 09 about 2 mm rutting and in test 10 less than 4 mm rutting could be seen on the road surface.

Rutting is so little that no conclusion could be drawn between studied structures.

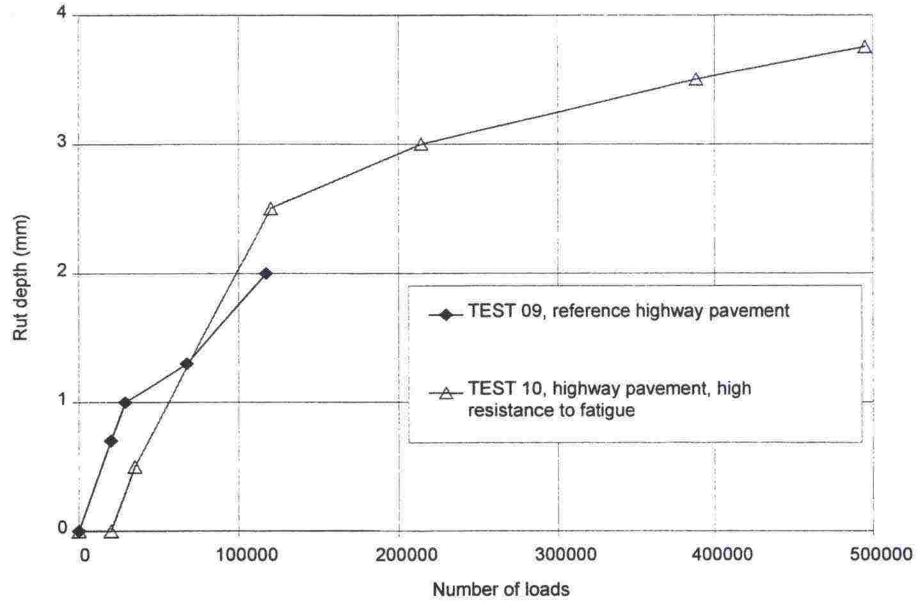

Figure 44. Rut depths vs. number of passes in conventional structure (test 09) and in innovative structure (test 10), 60 kN bi-directional dual wheel load for both tests.

Figure 45 shows a comparison of the effect of bituminous layer thickness on rutting. The wheel load was the same in both tests. In test 10, which has 110 mm bituminous layers, rutting is about one third compared to that of test 01, which had only 50 mm bituminous layers.

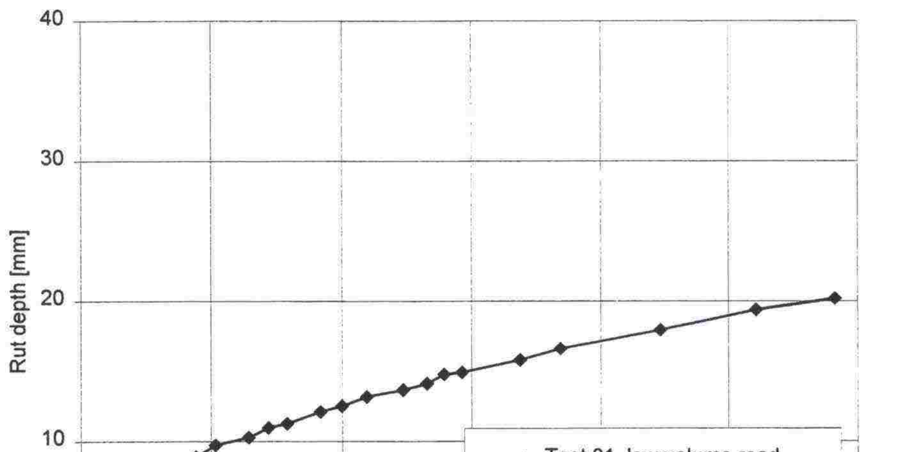

Figure 45. Rut depths vs. number of passes, test 01(50-mm bituminous layers, 60 kN dual wheel load) and test 10 (110-mm bituminous layers, 60 kN dual wheel load).

4.1.2. Cracking

These tests were interrupted because the HVS was transported to Sweden for the VTI tests. Only 0.12 million load repetitions on test 09 and 0.50 million load repetitions on test 10 were made, which naturally was why no cracks were found.

4.2. Relative lifetime of test pavements

However, the structures could be compared to each other. First, the initial response measurements were taken into account. The measured strains at the bottom of the bituminous layers were 154 μS for the conventional structure, and 190 μS, for the innovative structure.

Bisar calculations were made for real layer thickness and using laboratory-defined stiffness moduli values for each material. The results were respectively 150 μS and 208 μS.

After that, Bisar calculations were made for the planned thickness (110 mm) for both structures. The results were 188 μS and 221 μS, respectively.

The measured response values were calculated with the relation of Bisar calculations of planned and real thickness. The results were 193 μS and 202 μS, respectively.

Based on these response values and laboratory fatigue criteria, the innovative structure had 30 times better resistance to traffic loading.

The calculations described above are given in Table 3.

Table 3. Calculations of relative lifetime of test structures.

Strain at the bottom of bituminous layers (μS)	Conventional structure	Innovative structure
Measured (actual thickness)	154	190
Bisar (actual thickness)	150	208
Bisar, (110 mm thickness)	188	221
Calculated (Measured, Bisar)	(188/150)*154=193	(221/208)*190=202
Evaluated lifetime (laboratory fatigue)	3M	90M

The calculations were based on 10 °C temperature values. If the calculations are made with, e.g., 20 °C temperature response values, the difference is much greater.

However, the construction costs of bituminous layers were only 10 % higher for the innovative structure. The same lifetime as the 110-mm thick conventional structure has can be obtained with an 80-mm (40 +40 mm) thick innovative structure. The calculations are made in a similar way as described above. Thus, the construction costs are 20 % lower for the innovative structure compared to those of the conventional one.

4.3. Life cycle cost analysis

A life cycle.cost analysis was made according to the TPPT method /9/. Only the bituminous layers were taken into account in the analysis because all the other layers were similar. A one kilometre long section, two lanes each 3.5 m wide and paved shoulders together 3.5 m wide was analysed.

The analysis period was selected to be 40 years with a discount rate of 6 %. The increase in maintenance and rehabilitation cost was estimated to be 2 % per year.

The costs of construction, maintenance and rehabilitation were given by an asphalt expert of Uusimaa district.

It was assumed that the third asphalt layer, SMA18/100 overlay will be made one year after the road was opened to traffic.

Only cracking and rutting were used for analysis; other maintenance and rehabilitation models were not included in that analysis.

The intervention level for cracking was calculated with the APAS program (Figure 46).

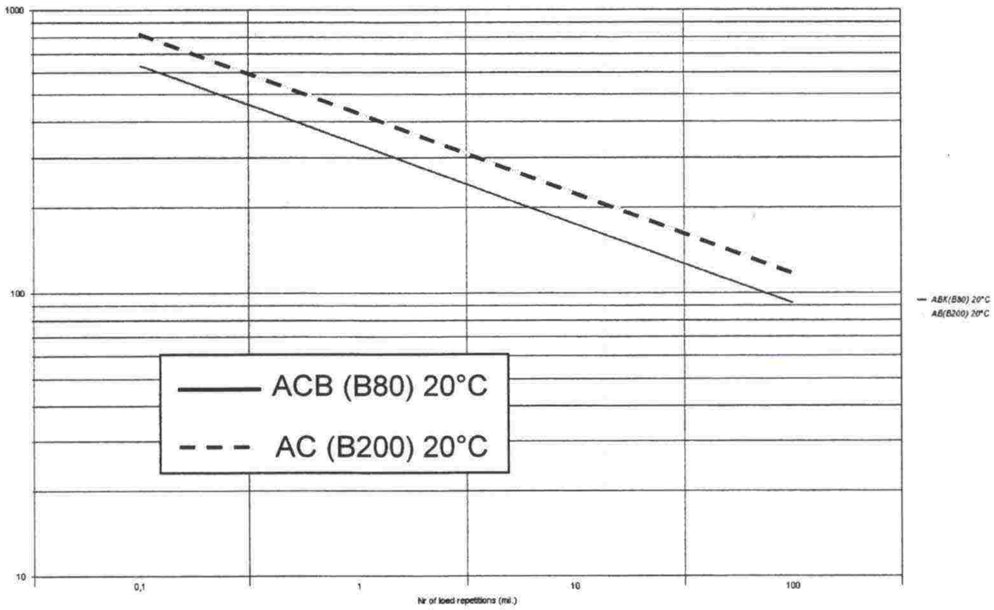

Figure 46. Fatigue criteria for AC (B200) and ACB (B80) materials according to APAS pavement design program /10/.

The intervention level for rut depth was determined as 14 mm according to road category. Rutting was evaluated with VTT models using as input road geometry, materials and traffic data. Traffic was estimated to distribute 60/40 % on right and left lane.

The AADT of Ring Road II is 35 000, and amount of heavy freight vehicles was assumed to be 8 %. Thus, the number of annual equivalent standard axle loads was 0.68 million.

Calculations were made for three structures:

- Conventional structure 110 mm bituminous layers
- Innovative structure 110 mm bituminous layers
- Innovative structure 80 mm bituminous layers

The fatigue life of the conventional structure and 80-mm innovative structure are the same.

According to the APAS calculations, the fatigue life of the conventional structure and 80-mm innovative structure was 20 years. The fatigue life of the 110-mm innovative structure was 53 years. The type of rehabilitation was selected to be overlay with SMA18/100.

The intervention level for rut depth was reached after every sixth year for the right lane and every eighth year for the left lane. The type of maintenance was selected to be Remixer.

The last maintenance cost was taken into account only partly, in linear relation to the time left until the end of analysis period. Thus, the effect of pavement preservation was cancelled.

Calculations of equivalent uniform annual cost (EUAC) for each structure are presented stage by stage in Appendices 3-5. EUAC is a key parameter when comparing different structures to each other for the road authorities.

The result of the analysis was, EUAC (FIM) :

- Conventional structure 110-mm bituminous layers 90 400
- Innovative structure 110-mm bituminous layers 85 300
- Innovative structure 80-mm bituminous layers 83 900

EUAC of the innovative structure with 110-mm bituminous layers was 6 % lower and with 80-mm bituminous layers 7 % lower than EUAC of the conventional structure with 110-mm bituminous layers, when the analysis was made based on the equivalent uniform annual cost (EUAC).

5. FUTURE RESEARCH

Based on the promising results of these HVS tests, Finnish Road Administration decided to construct a one-kilometre-long section of innovative structure on Ring Road II in Espoo. The layer thicknesses were similar to the plan tested with the HVS. The third SMA18/100 layer will be overlaid in summer 2001.

Both innovative and conventional sections were instrumented with eight asphalt strain gages, four pressure cells in base course and one deflection sensor.

Initial response measurements as well FWD measurements were made before opening to traffic. Longitudinal and transverse evenness was measured with a VTT road-monitoring vehicle.

Observations and measurements will be continued in the future at intervals that will be decided later on.

To develop an innovative structure, new test sections should be constructed. Thinner pavement should be tested with thicker conventional structure. New more cost-effective materials as binder course should be tested.

When designing roads, it is very important to consider the interaction between heavy vehicles and the pavement. When measuring pavement responses due to wheel load it is possible to develop models and pavement structures where the functional properties of each material can be used in an optional way, to benefit from the capacity of each material.

6. CONCLUSIONS

Two tests were made on the Ring Road II in Espoo. The structures of the tests 09 and 10 were for heavy trafficked highways. One structure was conventional and the other so called innovative structure with high resistance to fatigue. The aim was to study the effect of different materials and different location of bituminous layers in the structure to the pavement performance.

After initial response measurements 0.50 million loads were made on test 10, innovative structure. Less than 4 mm rutting could be seen on road surface and naturally no cracks. On conventional structure 0.14 million loads were made, similarly. About 2 mm rutting was found and no cracks, too.

The number of load repetitions were too little to effect cracks on road surface.

According to the experiences of these tests, the following conclusions could be drawn:

1. Within response measurements the difference between gages of same type was less than 5 %, so responses can be seen very reasonable.
2. Based on these response values and laboratory fatigue criteria, innovative structure had 30 times better resistance to traffic loading, relatively.
3. However, the construction costs of bituminous layers were only 11 % higher for innovative structure.
4. The same life time than 110 mm thick conventional structure has, can be reached with 80 mm (40 +40 mm) thick innovative structure. Calculations were made according to similar way described above. Thus the construction costs were 17 % lower for innovative structure compared to those of conventional one.
5. According to APAS calculations, the fatigue life of innovative structure was twice compared to that of conventional one.
6. When the third asphalt layer, SMA18/100 was taken into account, the fatigue life of conventional structure and 80 mm innovative structure were 20 years. The fatigue life of 110 mm innovative structure was 53 years.
7. Innovative structure with 110 mm bituminous layers was 6 % and with 80 mm bituminous layers 7 % more economic compared to conventional structure with 110 mm bituminous layers, when analysis was made based on equivalent uniform annual cost (EUAC).

The materials and the structure of innovative structure are well known and tested. There are no limitations to construct that kind of road pavements in practice.

7. REFERENCES

1. HVS-Nordic: Research Programme for full scale accelerated pavement testing in Finland and Sweden 1997-2003. Linköping 1998. 10 pp.
2. Huhtala Matti, Pihlajamäki Jari. HVS-NORDIC. The activity of the first period in Finland 1997-1999. Finnish National Road Administration, Finnra Reports 21/2000. 50 p. + 1 app. ISBN 951-726-638-3, ISSN 0788-3722, TIEL 3200609E. Helsinki 2000.
3. Finnish Asphalt Specification 2000. Finnish Pavement Technology Advisory Council (PANK). Helsinki 2000.

4. Apilo, Laura. Kantavan kerroksen asfalttibetoni, referenssimateriaalin ominaisuudet. TPPT-projekti M11, loppuraportti. VTT Yhdyskuntatekniikka. Espoo 1996. In Finnish.

5. Spoof, H., Asfalttipäällysteiden väsyminen. Asfalttipäällysteiden tutkimusohjelma ASTO 1987-1992. Valtion teknillinen tutkimuskeskus, Tie-, geo- ja liikennetekniikan laboratorio n:o 74. Espoo 1992. 57 p. In Finnish.

6. HVS-NORDIC: Sampling and Testing, Basic Minimum & Absolute Basic Minimum Programmes. VTI Swedish Road and Transport Research Institute. Linkoping 2000. 4 p.

7. Huhtala, M., Alkio, R., Pihlajamäki, J., Pienimäki, M. & Halonen, P., Behavior of Bituminous Materials Under Moving Axle Loads. Asphalt Paving Technology 1990, vol 59. Annual Meeting of the Association of Asphalt Paving Technologists, February 1990, Albuquerque, New Mexico. pp. 422-442.

8. Huhtala, M. & Pihlajamäki, J., New Concepts on Load Equivalency Measurements. Proceedings of the 7th International Conference on Asphalt Pavements. Volume Three. Nottingham 1992. pp. 194-208.

9. Ruotoistenmäki, A., Life-cycle Cost Analysis. Proceedings, the Finnish Road Structures Research Programme 1994-2001, TPPT Symposium, Espoo Cultural Centre Finland 8-9 June 1998. pp. 75-82.

10. Kuskelin, Arto, APAS – Analytical Pavement Design program manual. Finnish Road Administration. Helsinki 1998.

8. APPENDICES

Appendix 1	Initial measurements 1998 program (test 10, Ring II, Espoo, Finland).
Appendix 2	Overview of HVS test and results.
Appendix 3	HVS-NORDIC, life cycle cost analysis of Ring road II structures.

VTT / HVS- NORDIC

Initial measurements 1998 (example from test 10, Ring II, Espoo, Finland)

Super single:3 measurements/vehicle

Time order	Vehicle code	Tyre pressure (kPa)	Load (kN)	Speed (km/h)	Beam position (cm) *			Asphalt temp. (°C)
					0	-15	distribution	
1	H84	500	30	10	x			+10
2	H85	500	40	10	x			+10
3	H86	500	50	10	x			+10
6	H87	500	60	10			x	+10
4	H88	500	70	10	x			+10
5	H89	500	80	10	x			+10
8	H35	600	30	10	x			+10
9	H36	600	40	10	x			+10
10	H24	600	50	10	x			+10
13	H90	600	60	10			x	+10
11	H92	600	70	10	x			+10
12	H93	600	80	10	x			+10
14	H31	700	30	10	x			+10
15	H32	700	40	10	x			+10
16	H26	700	50	10	x			+10
19	H33	700	60	10			x	+10
17	H34	700	70	10	x			+10
18	H94	700	80	10	x			+10
20	H95	800	30	10	x			+10
21	H37	800	40	10	x			+10
22	H23	800	50	10	x			+10
25	H38	800	60	10			x	+10
23	H39	800	70	10	x			+10
24	H49	800	80	10	x			+10
26	H96	900	30	10	x			+10
27	H40	900	40	10	x			+10
28	H22	900	50	10	x			+10
35	H41	900	60	10			x	+10
29	H97	900	60	2	x			+10
30	H98	900	60	4	x			+10
31	H99	900	60	7	x			+10
32	K01	900	60	12	x			+10
33	H42	900	70	10	x			+10
34	H48	900	80	10	x			+10

APPENDIX 1.2(3)

Dual wheel: 3 measurement/vehicle

Time order	Vehicle code	Tyre pressure (kPa)	Load (kN)	Speed (km/h)	Beam position (cm)* 0	-15	distribution	Asphalt temp. (°C)
1	H71	500	30	10	x	x		+10
2	H72	500	40	10	x	x		+10
3	H05	500	50	10	x	x		+10
6	K02	500	60	10			x	+10
4	K03	500	70	10	x	x		+10
5	K04	500	80	10	x	x		+10
7	H73	600	30	10	x	x		+10
8	H74	600	40	10	x	x		+10
9	H04	600	50	10	x	x		+10
12	H75	600	60	10			x	+10
10	K05	600	70	10	x	x		+10
11	K06	600	80	10	x	x		+10
13	H11	700	30	10	x	x		+10
14	H12	700	40	10	x	x		+10
15	H06	700	50	10	x	x		+10
18	H13	700	60	10			x	+10
16	H14	700	70	10	x	x		+10
17	K07	700	80	10	x	x		+10
19	H76	800	30	10	x	x		+10
35	H76	800	30	10	x	x		+0
41	H76	800	30	10	x	x		+5
47	H76	800	30	10	x	x		+15
53	H76	800	30	10	x	x		+20
20	H54	800	40	10	x	x		+10
36	H54	800	40	10	x	x		+0
42	H54	800	40	10	x	x		+5
48	H54	800	40	10	x	x		+15
54	H54	800	40	10	x	x		+20
21	H03	800	50	10	x	x		+10
37	H03	800	50	10	x	x		+0
43	H03	800	50	10	x	x		+5
49	H03	800	50	10	x	x		+15
55	H03	800	50	10	x	x		+20
22	H18	800	60	10			x	+10
38	H18	800	60	10			x	+0
44	H18	800	60	10			x	+5
50	H18	800	60	10			x	+15
56	H18	800	60	10			x	+20
25	K09	800	60	2	x	x		+10

APPENDIX 1.3(3)

	Vehicle code	Tyre pressure	Load	Speed	Beam position (cm)*			Asphalt temp.
		(kPa)	(kN)	(km/h)	0	-15	distribution	(°C)
26	K10	800	60	4	x	x		+10
27	K11	800	60	7	x	x		+10
28	K12	800	60	12			x	+10
23	H55	800	70	10	x	x		+10
39	H55	800	70	10	x	x		+0
45	H55	800	70	10	x	x		+5
51	H55	800	70	10	x	x		+15
57	H55	800	70	10	x	x		+20
24	H56	800	80	10	x	x		+10
40	H56	800	80	10	x	x		+0
46	H56	800	80	10	x	x		+5
52	H56	800	80	10	x	x		+15
58	H56	800	80	10	x	x		+20
29	K08	900	30	10	x	x		+10
30	H77	900	40	10	x	x		+10
31	H02	900	50	10	x	x		+10
32	H78	900	60	10			x	+10
33	H79	900	70	10	x	x		+10
34	H80	900	80	10	x	x		+10

*) Beam positions:

0 = centere line of test section

super single distribution: from -35 to +35 cm in 5 cm steps

dual wheel distribution: from -25 to +25 cm in 5 cm steps

negative values are side shifts to left in centimeteres

positive values are side shifts to right in centimetres

ISSN 1457-9871
ISBN 951-726-764-9
TIEH 3200675E